

THE RELATIONSHIP BETWEEN URBANIZATION AND STREAMFLOW
IN THE HILLSBOROUGH RIVER BASIN, 1940-1970

By

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DEDICATED TO:

Ellen

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The major objective of this research was to determine the impact of urbanization on the hydrologic component of streamflow in the Hillsborough River Basin between 1940 and 1970. A brief look at the runoff process within the Hydrologic Cycle along with a general discussion of similar research in other regions was helpful in determining several possible relationships in the study area. Final results were based on field observations and multiple methods of analysis of precipitation and streamflow data.

Before determination of the basic relationship could be made, it was necessary to establish the hydrologic character of the region. The climatological and geological settings were therefore determined. Because of the variable nature of precipitation on the 690 square mile study area, average rainfall was calculated by using data from seven recording stations and constructing the respective Thiessen polygons. In addition, the relative

distribution of available water within the region was based on temperature relationships along with adjusted precipitation figures according to the Thornthwaite water balance.

Several limiting factors such as large basin size, relative extent and location of urban area, and tidal influence on the streamflow recording gauge, necessitated the selection of two subareas for analysis. The Blackwater Creek Basin was used as a rural control because of the noticeable lack of urban development in the region. The Alligator Creek Basin, although located fifteen miles west of the major study area was selected as an urban subregion because of its physical and developmental similarities to the urban portion of the Hillsborough River Basin.

The historical developmental patterns of the major study area and the subregions were examined to determine the relative extent of urbanization. In addition, the recurrence of flood and drought periods was also examined and related to the major water problems of the region. Analysis of the 1962 Army Corps of Engineers' Four River Basins Project, along with its major revisions, revealed the relative usefulness of the provisions of this program.

The streamflow response to precipitation was examined in both the Blackwater Creek and Alligator Creek Basins by the use of three methods of analysis. These

were: 1) Storm Hydrograph Analysis, 2) Cumulative Curve Analysis, and 3) Regression Analysis. Investigations revealed that increased urbanization in the study area has increased streamflow in the Hillsborough River Basin. In addition, comparative results from regression analysis determined that over 33 percent of the variation in streamflow in the urban basin was explained by urban development.

The results from this study have shown that increased urbanization has generally increased streamflow. However, localized field observations have also shown that increased surface runoff has decreased ground water recharge, thus decreasing base flow during low flow periods. Overall, increased urbanization in the study area has intensified the regional water problem. General recommendations for the regional water program include implementation of the revised F.R.B. Plan along with local modifications to provide for increased surface water retention and local ground water recharge.

CHAPTER I

INTRODUCTION

Recently, Florida's population has been one of the fastest growing in the country. However, the pattern of population is not uniform as some regions have witnessed much greater increases than others. Since 1960, population growth within the tri-county area of the Tampa Bay Region (Hillsborough, Pinellas, and Pasco) has accounted for a large portion of the overall increase in population; thus resulting in Florida's present status. Analysis of the statistics in Table 1 will indicate the rate and basic distribution of population growth within the region since 1940.

Population in the Tampa-St. Petersburg Standard Metropolitan Statistical Area has increased considerably within the period of record.* The 1970 census data show that between 1960 and 1970, population increased 31.1 percent in this area. This figure, however, does not present the true spatial distribution of growth within the region. Further inspection of the data will reveal

*SMSA was not used until the 1960 Census. For convenience of comparison, SMSA for 1940 and 1950 includes summation of data for Hillsborough and Pinellas Counties and Tampa-St. Petersburg Inner Cities.

Table 1: Population of Florida and the Tampa Bay Region: 1940-1970

Area	1940	1950	1960	1970	Period Trend Percent Inc. 1940-1970	Recent Trend Percent Inc. 1960-1970
Florida	1,897,414	2,771,305	4,951,560	6,789,443	258%	37.1%
Tampa	108,391	124,681	274,970	277,767	157%	1.0%
St. Petersburg	60,812	96,738	181,298	216,232	256%	19.3%
Hillsborough County	180,148	249,894	397,788	490,265	172%	23.2%
Pinellas County	91,852	159,249	374,665	522,329	468%	39.4%
Pasco County	13,981	20,529	36,785	74,955	443%	106.5%
SMSA (Hillsborough, Pinellas)	272,000	409,143	772,453	1,012,594	272%	31.1%
SMSA - Inner City	169,203	221,419	456,268	493,999	192%	8.3%
SMSA - Outside Inner Cities	102,797	187,724	316,185	518,595	404%	64.0%

Source: Bureau of the Census, 1971

that during this period, the inner cities increased only 8.3 percent while the population of the fringe areas or counties increased at the rate of 64 percent (Bureau of the Census, 1971). It is doubtful that this 64 percent increase resulted from a purely rural population. Rather, it has been caused by suburban development.

Recent urban development within the Tampa Bay Region, therefore, has transcended traditional boundaries. Accommodations for this new population since 1940 have changed the basic land use pattern of the area. The effect that these changes have had on the hydrological systems of the Hillsborough River Basin is the subject of this paper.

Location of the Area

The Hillsborough River Basin is located in the west central portion of the State of Florida (Figure 1). The river rises in the Green Swamp just north of the city of Lakeland where it is separated from the Withlacoochee River by a low topographic saddle. During periods of high water, both rivers share a common source. From the Green Swamp, the Hillsborough River flows predominantly to the southwest for fifty-four miles until it enters Hillsborough Bay at Tampa. The river drains a watershed of approximately 690 square miles, including portions of Hillsborough, Polk and Pasco Counties.

The major tributaries to the Hillsborough River include Blackwater Creek, Pemberton Creek and Flint Creek

on the south and Cypress Creek, New River and Trout Creek on the north. Blackwater Creek rises west of Lakeland and flows to the river just east of the Hillsborough River State Park. This tributary drains a watershed of approximately eighty-six square miles. Pemberton Creek rises just north of Plant City and empties into Lake Thonotossassa. Flint Creek is an outlet to this lake and flows northward to the Hillsborough River. Together, Pemberton Creek and Flint Creek drain a sixty-five square mile basin.

Of the northern tributaries, Cypress Creek is the largest draining about 165 square miles. It rises in Pasco County northwest of San Antonio and flows southward to the Hillsborough. New River begins near St. Leo and joins the main river just west of the state park. Along with Trout Creek which rises near Wesley Chapel, these two tributaries drain a basin of about 135 square miles (Watson and Company, 1967).

Figure 1 shows the spatial distribution of urban centers within and around the Hillsborough River Basin. In addition, this map shows the location of Alligator Creek near Safety Harbor, Florida. It should be noted that Alligator Creek is outside the study area. It is treated in this study because it is believed that to do so will clarify hydrologic relationships. This Creek drains a relatively small, but highly urbanized area of about nine square miles on the Pinellas Peninsula.

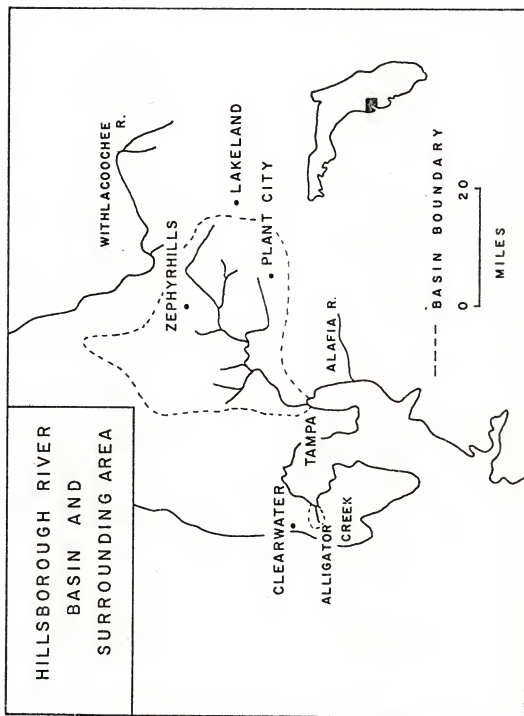


Figure 1

Further discussion of the use of Alligator Creek will be found later in this chapter.

Urban Effects on Hydrological Systems

Urban Trends

Since 1900, the population of the United States has tended to concentrate in cities and around urbanized areas (Murphy, 1966). At one time, it was necessary to live in a city in order to enjoy the conveniences and services of the central business district. Recently, however, the rate at which our major cities have grown, has declined in comparison with their related urban fringes. Table 2 compares urban growth with urban fringe growth and illustrates the trend of population movement from 1960 to 1970.

Table 2: Population Growth Within Standard Metropolitan Statistical Areas: 1960 to 1970

Location	1970	1960	Increase 1960-1970	
			Number	Percent
In SMSA's	139,418,811	119,594,754	19,824,057	16.6
In Cent. Cities	63,796,943	59,947,129	3,849,814	6.4
Out of Cent. Cities	75,621,868	59,647,625	15,974,243	26.8

Source: Bureau of the Census, 1971

Movement to the suburbs in the last ten to fifteen years has increased rapidly for several reasons. The

development of better transportation systems and the shopping center concept have made suburban living more convenient. Outside of corporate boundaries, taxes are considerably lower and most people find open space a pleasant change from the crowded city. Many of the city's advantages are now found in the suburbs. Shopping centers provide services and convenience, replacing the function of the C.B.D. without the related problems of traffic and congestion.

Although there are many advantages to living outside of central cities, there are also several social and economic disadvantages.* For this reason, many geographers, sociologists and other social scientists have examined the rural-urban fringe (Wehrwein, 1942) in great detail. However, traditional studies of this area have been limited to delineation of the region and discussion of the social and economic implications of urban encroachment on agricultural land.

This conventional approach has been exemplified by several authors such as Wehrwein (1942), Blizzard (1954), and Murphy (1964). Until recently, geographers have neglected studying the effects of rural-urban land use changes on physical and hydrological systems. Most of

*It is beyond the scope of this paper to discuss the problems of urban fringe areas in any detail. However, it should be mentioned at this point that the major disadvantages of urban fringe living are usually found in the lack of zoning regulations and the often insufficient provision of county fire and police protection (Murphy, 1966).

this research has been done by civil engineers, geologists (urban hydrologists), and to a lesser extent, climatologists. Consideration of the "Hydrologic Cycle" as an integral part of Physical Geography and the recognition of Urban Geography as a viable segment of the discipline, justify classifying this type of study as geographic in nature.

Many geographers consider urbanization of a region to include the development of residential, commercial and industrial areas. Such land use changes in transforming a formerly natural or agricultural area would appear to modify considerably the natural hydrologic characteristics of that region or watershed. Direct runoff and streamflow are also noticeably affected.

Possible Relationships

Construction of roads, parking lots and structures related to urbanization can decrease the surface area of the basin capable of absorbing precipitation. Increases in streamflow can result from this additional impervious surface area. Also, less surface water is lost to infiltration and ground water recharge, thus creating an additional increase in direct runoff.

Increased urbanization may on the other hand, decrease streamflow in a river basin. This relationship can result from an actual decrease in surface area drained by a particular river. Unnatural drainage patterns are frequently created by man-made drainage channels.

Sometimes these divert a portion of direct runoff to a neighboring basin. This decrease in catchment area can subsequently decrease streamflow. There is at the same time a likelihood of artificial increases.

A third relationship between urbanization and streamflow may be possible. Urban development may have no net effect on direct runoff within a given watershed. If the basin area was sufficiently large and the urban development was limited to a relatively small portion of the total area, the hydrologic response to urbanization might be insignificant. Also, net increases in direct runoff due to land use change may be negated by factors which tend to decrease runoff. This relationship would also result in a negligible change in streamflow.

Basin alterations due to increased urbanization may in effect create an overall change in the regime of flow of a river. For the most part, this effect would be best seen in the hydrologic response of streamflow to storm runoff. Increased impervious surface area tends to increase the rate at which peak flows are attained and decrease their relative duration. A more detailed discussion of possible regime changes will be found later in this chapter and in Chapter V. First, a brief analysis of the runoff process is necessary for a better understanding of the effects of urban development on streamflow.

The Runoff Process

Direct runoff is that portion of precipitation that flows over the surface of the earth in thin sheets (overland flow) or in systematized channels. The amount of direct runoff from any given storm is dependent upon several factors such as precipitation intensity and duration along with surface configuration of the basin. (The latter may be considered a function of physical makeup, climatic situation and cultural activity.) When precipitation reaches the earth, it may either be stored on the surface, infiltrate through the soil, or flow overland. The first aspect of the runoff process to be considered will be surface storage.

Surface detention is the net water loss to runoff created by interception and depression storage. In the initial stage of a storm, a large portion of the rainfall is intercepted by vegetation and cultural structures. Some of this moisture is quickly evaporated and never reaches the ground. The amount of rainfall originally lost to interception in a natural watershed is dependent upon the type and density of vegetation present. Horton (1919) developed a method to calculate the amount of water intercepted during any given storm. This quantity may be determined according to the formula:

$$I = a + b P^n$$

where I is equal to Interception, P is equal to total

precipitation in inches and a , b , n are constants derived from differing types of vegetation (Horton, 1919). Table 3 lists the constants for several selected types of vegetative cover.

Kittredge observed that between 2 and 40 percent of the total rainfall from a storm may be initially lost to interception within a well developed forest. He found, in his 1937 study, that within a forest of Australian Eucalyptus, only 2 to 3 percent of precipitation was intercepted, while in an area covered by California Hemlock and Douglas Fir up to 40 percent of the moisture was initially prevented from reaching the ground (Bruce and Clark, 1969; Horton, 1919). From these studies, it is evident that the role of interception of rainfall by natural vegetation is significant in the runoff process.

As precipitation continues, the storage capacity of the natural cover is satisfied and stem flow and drip occurs, allowing a greater proportion of moisture to reach ground level. Water then begins to infiltrate, adding to soil moisture and subsequently to ground water recharge. Depression storage does not occur until the soil has become saturated (satisfying soil moisture capacity) or until the rainfall intensity exceeds the infiltration rate of the basin surface. At that point, the smallest depressions within the basin begin to fill, coalesce and spill over into larger depressions.

Table 3: Values of Constants in Horton's Interception Equation

Vegetation	a	b	n
Orchards	0.04	0.18	1.00
Oak Woods	0.05	0.18	1.00
Maple Woods	0.04	0.18	1.00
Willow Shrubs	0.02	0.40	1.00
Hemlock and Pine Woods	0.05	0.20	0.50
Clover and Meadowgrass	0.005h*	0.08h	1.00
Small Grains, Rye, Wheat, Barley	0.05h	0.05h	1.00

*h - height of plants (in feet)

Source: Bruce and Clark, 1969; Horton, 1919

Ultimately, all of the depressions fill and direct runoff in the form of sheetwash and streamflow begins. It should be considered, however, that water held in depression storage does not go directly to runoff. Water stored in this method is held in place (such as in large flats or marsh areas) until such a time that it evaporates or infiltrates, replenishing soil moisture or the ground water table. The amount of water held in depressions is inversely proportional to the infiltration rate and slope of the basin. In most areas, water will readily flow over a surface with significant relief, thus decreasing the overall amount of surface water retention and total infiltration within the basin. In karst areas, however, this relationship between relative slope and infiltration is altered somewhat by the porous characteristics of surficial material and the bedrock complex. Therefore, with

the exception of many karst regions, slope is an important factor governing the infiltration rate.

Infiltration is the movement of surface water into the pore spaces and openings of the soil. The amount of precipitation allowed to infiltrate during a particular storm can be measured quantitatively (Horton, 1939). However, this study will be concerned only with empirical increases or decreases in the infiltration rate caused by changes in land use. In addition to slope, the other factors affecting this rate are; frequency and intensity of precipitation along with the related soil moisture content, physical characteristics of the soil and vegetative cover.

Soil moisture is interrelated with the other factors governing the infiltration rate. It is considered to be the amount of water held in the soil, equal to the total of hygroscopic and capillary water. Major depletions to soil moisture are caused by percolation to ground water, use by vegetation (photosynthesis and transpiration) and evaporation caused by capillary movement of water to the surface during dry periods. If sufficient time elapses between storms for these processes to operate effectively, soil moisture capacity will be increased, thus increasing potential infiltration. If the time period is short, however, soil moisture capacity will be satisfied quickly and the infiltration rate will decrease. In this circumstance, the effect is to shorten the lag time before runoff occurs.

Soil moisture and infiltration capacities are also dependent upon the physical characteristics of the soil. Coarsely textured soils (sand) have a greater percentage of pore space than fine textured soils (clay). For this reason, they have a greater ability to absorb moisture and their occurrence increases the amount of infiltration within a watershed. In addition to their fine texture, clay soils usually contain a relatively high percentage of colloidal material. This causes the individual particles of clay to swell during periods of wetting, further decreasing their pore space and ability to infiltrate moisture. Besides texture, infiltration is affected by the compactive nature of the soil. Tightly packed soil created by rain striking barren ground or by the activity of man and animals, can greatly decrease pore space in the soil, thus decreasing its ability to soak up moisture. The impact of this condition, however, may be minimized by the presence of vegetation.

It has been found in several cases, that the type of vegetation present in an area is more significant in determining infiltration capacity than soil type (Wisler and Brater, 1967). A dense cover of vegetation is known to rapidly increase the infiltration rate. The protective cover of vegetation intercepts large volumes of water during a storm, thus decreasing the effective intensity of precipitation and preventing soil compaction. In addition, vegetation tends to separate soil particles with

its roots and provides an environment where the action of animals and insects can, in effect, aerate the soil. In each instance, additional pore space is created, thus increasing the infiltration capabilities of the basin surface. It should be remembered that each factor which tends to increase infiltration also tends to decrease direct runoff and streamflow within the basin.

The final aspect of the runoff process to be considered is that of systematized channel flow or streamflow. Streamflow may be divided into two major components; direct runoff and base flow. During storm periods, the leading contributor to streamflow is direct runoff which was discussed earlier with respect to infiltration and surface storage. Base flow, however, is that portion of water supplied to a river during periods when direct runoff is lacking. It consists of indirect runoff (subsurface flow) and ground water seepage (Figure 2).

Indirect runoff is the net movement of water beneath the basin surface. It is the result of two primary factors; gravity movement of soil moisture and the movement of ground water. (In karst regions, the movement of water through subsurface streams must also be considered.) In each case, the amount of indirect runoff is directly proportional to the infiltration capabilities of the basin surface.

In a similar sense, the level of the ground water table is a function of infiltration. Reduced percolation of surface water will ultimately result in extensive ground

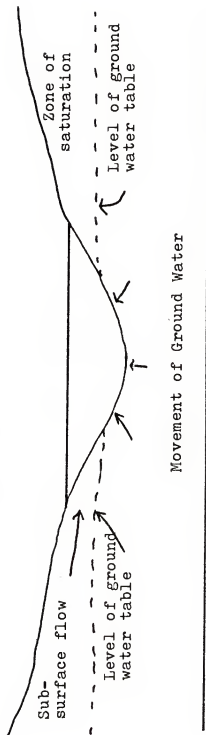


Figure 2: Components of Base Flow

water depletion, thus decreasing this component of base flow. During long dry periods, streamflow may be sustained solely by ground water seepage. If the ground water table is lowered sufficiently by reduced recharge during wet periods, or by overuse of the resource, streamflow during droughts may cease completely. Notably, subsurface water is an important segment of the streamflow process in an effluent stream (Hillsborough River) and is directly affected by land use changes in the basin.

This brief discussion of the runoff process illustrates the delicate balance of the hydrologic cycle. When urbanization takes place, several factors of this cycle are altered, thus disturbing this natural balance. Students of hydrology have become aware of the implications of rural-urban land use changes. Most texts in the discipline include a general discussion of the effects of land use changes on the hydrologic cycle. Only recently, however, have studies focused on the exact relationship of urbanization and streamflow within specific hydrologic regions.

Research

Urbanization is known to have a considerable impact on local hydrologic systems. Much of the literature on this subject has been concerned with the urban effects on climate as well as surface and ground water hydrology. Because of the importance of evapotranspiration and the nature of precipitation on the runoff process, climatic modification or alteration due to urban expansion must

be considered in a study of this type. Landsberg (1956) concluded that increased urbanization has affected the microclimatology of several European regions. His findings from additional investigations which are summarized in Table 4, reveal that there is a significant variance in precipitation, temperature, humidity and wind speed over urban, compared to rural areas.

There is little question that precipitation changes have a direct effect on runoff. Increases in precipitation will also add to soil moisture, ground water recharge and subsequently to the components of streamflow. However, if the characteristics of total rainfall are changed, producing frequent storms of light intensity and short duration, total runoff may decrease. The portion of water lost to evaporation, infiltration and percolation from a storm of this type is dependent upon the surface characteristics of the basin.

Most of the literature concerning the relationship between surface characteristics and runoff has been written in the last ten to fifteen years. In 1961, the United States Geological Survey published the first chapter of a five chapter water supply paper entitled, Hydrologic Effects of Urban Growth.* In Chapter A, Savini and Kammerer

*The five chapters of this water supply paper were published under separate covers and are listed under U.S.G.S. Water Supply Papers 1591A-E.

Table 4: Climatic Variance Over Urban Areas

Climatic Component	Urban Variance	Attributed to
Precipitation		
Total	+5 to 10%	Increase in air pollution - particulates and condensation nuclei
Frequency	+10%	
Temperature		
Annual Mean	+1.0 - 1.5°F	Increased convection
Winter Min.	+2 to 3°F	
Relative Humidity	-6%	Decrease in evapo-transpiration
Wind Speed	-20 to 30%	Increased surface friction

Source: Bruce and Clark, 1969; Landsberg, 1961

discussed the general effects urban growth had on the water regimen. They reported that urbanization had a tendency to significantly change local characteristics of evaporation, transpiration, infiltration and ground water recharge. The authors credited these changes to three basic alterations of the natural environment: 1) decreased opportunity for infiltration, 2) reduced vegetation and 3) change in surficial cover.

Although the general effect was characterized by a decrease in these processes, Savini and Kammerer also reported possible increases in these processes due to urban expansion. In most cases, these increases resulted from the addition of imported water to the basin. This water,

used for household consumption, landscape maintenance, and waste water disposal, acted as an artificial source to the hydrologic system. The increased use of water also tended to deplete the ground water table and increase the quantity, but decrease the quality of streamflow.

Waananen (1969) refers to an Illinois study in which two nearby drainage basins (one rural, one urban) were compared for sustained flow during dry periods. During wet years, streamflow was essentially equal in both situations. In dry periods, however, the urban basin maintained a much higher level of flow than the rural basin. This reaction resulted from two hydrologic differences in the sample areas. The rural basin experienced a greater portion of water loss to evapotranspiration due to the dominance of vegetation. Also, streamflow in the urban basin was influenced by decreased infiltration and the addition of urban waste water to the system.

Additional studies have been concerned with the influence that urban environments have on peak and low flows. Research has shown that in the Salt Creek Basin within the metropolitan area of Chicago, urbanization has increased the intensity, but decreased the duration of peak flows (Spieker, 1970). This hydrologic response has been attributed to an increase in the amount of impervious surface area and storm drainage systems within the basin. The amount of water during low flows has also increased, but for the most part consists of sewage effluent. In an

earlier study of Assunpink Creek in central New Jersey (Miller, 1966), sewage disposal accounted for over 60 percent of streamflow during dry periods.

Urban development, it has been demonstrated, affects the timing and distribution of runoff and peak flows. Assunpink Creek is located in an 89 square mile basin with a considerable urban area found downstream from rural land. The recording gauge on this stream is located downstream from the developed portion of the basin. Therefore, streamflow measurements reflect both the urban and rural response to storm runoff. Figure 3 represents a storm hydrograph developed by Miller in his study of this region. Inspection of the hydrograph shows two distinct peaks caused by a short high intensity storm in 1950. The first peak (530 cfs), which was reached very quickly, but had a short duration, illustrates the hydrologic response to urban runoff. The second peak (270 cfs), which was reached much slower and maintained for a longer period of time, is characteristic of rural hydrologic response and was created from runoff in the upper reaches of the basin.

Seaburn (1969) also used hydrograph analysis as one method of determining the effect of urbanization on the timing and distribution of direct runoff in East Meadow Brook, Long Island. Figure 4 illustrates two one-hour unit hydrographs taken from runoff measurements recorded during two distinct periods of urban development in the study area. For this study, Seaburn used total acres served

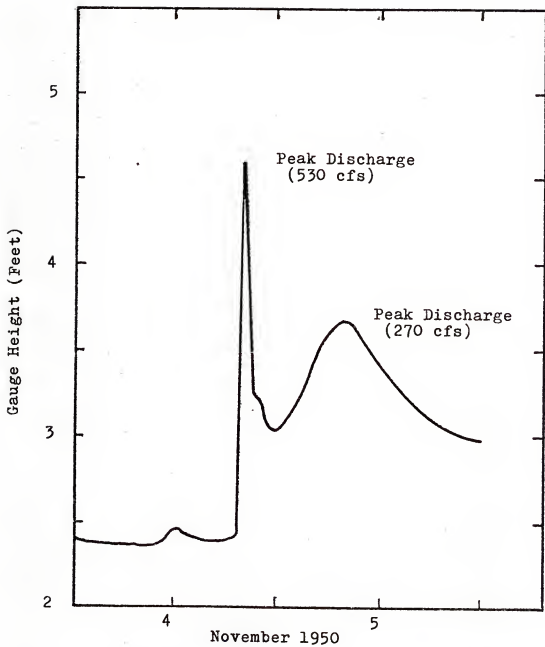
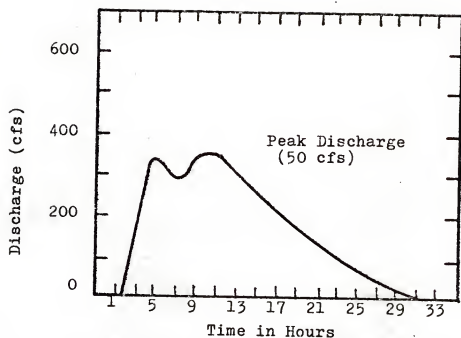
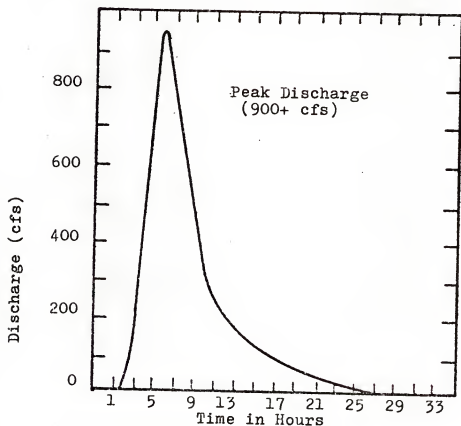


Figure 3: Storm hydrograph - Assunpink Creek (Waananen, 1969; Miller, 1966)



A. Storm hydrograph, 1939, 10% urban



B. Storm hydrograph, 1962, 56.2% urban

Figure 4: Hydrograph Comparison - Two periods of urban development in East Meadow Brook Basin (Seaburn, 1969).

by storm sewers as the total urban area of the region. Hydrograph A was developed from a storm in 1939 when only ten percent of the area was sewered. Hydrograph B, however, shows the distribution of direct runoff in 1962 when 56.2 percent of the area was served by storm sewers. Comparison of the hydrographs illustrates that as urbanization increased in East Meadow Brook Basin, peak flows from storm runoff increased in intensity, but decreased in duration.

Because most natural channels are adjusted to accommodate average flow, rapid development of unusually high peak flows increases the possibility of flooding in urban areas. For this reason, the primary concern of many urban hydrologists has been related to the increase in storm and flood flows caused by urbanization (Waananen, 1969). Most of the literature concerned with the effects of urban development on streamflow has reported marked increases in peak flows and reductions in low flows along with their related impact on annual water yields in urban areas (Bigwood and Thomas, 1955). Wilson (1967), however, was not merely concerned with the realization that increased development increased the frequency of river flooding. Rather, he was interested in the quantitative relationship between flood stage and the degree of urbanization within the basin. In his study near Jackson, Mississippi, he found that within a totally urbanized basin, the mean annual flood increased by a factor of 4.5 over a similar

rural situation while the magnitude of a fifty year flood increased only three times. Wilson therefore determined that the effect of urbanization on floods decreased with increasing flood magnitude.

Numerous computer models have been developed to predict what effect changes in specific components of the hydrologic cycle will have on streamflow. The School of Engineering at the University of South Florida has recently completed the first step in construction of such a model. Further additions and refinements, however, are necessary before it will be useful as a regional planning tool. James (1965) used the Stanford Watershed Model in researching the effects of urbanization on Morrison Creek in Sacramento County, California. His test results have shown the model to be reasonably accurate when they were compared to observed data and frequencies.

In almost every case study, current research in urban hydrology has shown increases in direct runoff caused by expanded urban development. It should be remembered, however, that this common result should not be considered the only possible result in all situations. As previously stated, urban modifications to the physical landscape or a river basin may result in decreased or unchanged streamflow. It is the purpose of this study to determine the hydrologic impact of expanded urbanization in the Hillsborough River Basin since 1940.

Scope of the Study

The previous discussion of the population growth in the Tampa Bay Region has concluded that since 1940 there has been significant urban growth in the Hillsborough River Basin. Alterations of the natural environment have been associated with the expansion of urbanized area. The objectives of this study are to: 1) Analyze the physical and hydrological systems of the region, 2) Examine the rate and distribution of urban growth within the region and 3) Determine the net effect of urban development on the hydrologic characteristics of the Hillsborough River System (primarily the component of streamflow).

Subregions

Examination of the hydrologic response of the entire Hillsborough River Basin to increased urbanization has been hampered by three interrelated characteristics of the region. These are: 1) size, 2) percent and location of urban area and 3) tidal influence. The Hillsborough River drains an area in excess of 690 square miles. Precipitation over the basin varies considerably because of its spatial extent and climatic situation. Also, the hydrographic response to storm runoff within most large basins is characterized by low broad "peaks" which at times are difficult to analyze on the unit hydrograph.

Although urban development has increased to a great extent in the area, the vast majority of land in the basin is still rural in nature. Therefore, it is contended that

consideration of the entire water regime would lead to results common to those of a rural or agricultural basin. The major urban development is found near the mouth of the river and historical expansion due to the urban sprawl of the city of Tampa has proceeded upstream. The total urbanized area of the basin, however, only accounts for a small portion of the total 690 square miles. Initial observation of the distribution of land use categories within the study area is somewhat similar to that of Miller's Assunpink Creek Study in central New Jersey. Viable streamflow data from the urban environment, however, is not available because most development has taken place below the Hillsborough River dam where the river is tidally influenced.

Because of these considerations, two subareas within the Tampa Bay Region have been selected for analysis and comparison. These are Blackwater Creek and Alligator Creek near Safety Harbor, Florida. Blackwater Creek was chosen as a rural sub-basin and will be used as a comparative control in the study. Urban development in this 89 square mile basin has been non-existent throughout the period of record. Therefore, streamflow fluctuations should be controlled by variance in precipitation and potentiometric surface, rather than by land use change.

Selection of the second sub-basin was more difficult because of the specific requirements necessary for the study. This area had to be sufficiently small for analysis, possess useful streamflow data for a minimum of twenty years

and have significant urban growth within the period of record. An area meeting all of these requirements and within the boundaries of the Hillsborough River Basin was not available. Alligator Creek was chosen because, in addition to meeting each of these criteria, it was within fifteen miles of the major study area and located in a region similar physiographically to the urbanized portion of the Hillsborough River Basin.

Method of Analysis

Precipitation and streamflow data have been collected for both subareas along with statistics for urban development within the Alligator Creek Basin for the period of record. Three basic methods of analysis will be used to determine the relationship between urbanization and streamflow in the Hillsborough River Basin. (Because of their proximity and physical similarity, Alligator Creek will be equated with the urbanized area of the major study region and the results obtained will be expected to be characteristic to both.)

The first method of analysis will involve a two-fold storm hydrograph comparison. First, hydrographs from the urban basin during different periods of development will be analyzed for significant variation in streamflow. Secondly, storm hydrographs for Alligator Creek will be compared to a hydrograph from Blackwater Creek. In each case, peak flows will be examined to determine the rate at

which they occurred along with their relative intensity and duration.

The second method of analysis will include a graphic comparison of the urban and rural streamflow regimes with respect to precipitation. This presentation will involve plotting cumulative precipitation against cumulative stream discharge for both subareas for the period of record. Comparison of the slopes of each plot will determine if any significant variance exists between the rural control and the urban basin.

The last method of analysis to be used in this study includes several basic statistical tests. These processes will not only reveal the existence or non-existence of a relationship, but also the extent to which the tested components of the hydrologic cycle affect streamflow, within a given level of confidence. It is expected that this last method of analysis will further define any relationship determined by the first two procedures.

CHAPTER II

PHYSICAL SETTING

Although Florida is the second largest state east of the Mississippi River, peninsular Florida exposes less than one half of the continental margin known as the Floridan Plateau. The basement complex of this physiographic feature is composed predominantly of Precambrian crystallines, similar to those of the Appalachian Provinces to the north. The presence of this ancient core, covered by more recent sedimentaries, suggests that the plateau has long been a part of the North American Continent with, however, only recent emergence of the Florida Peninsula (Thornbury, 1967).

In particular locations, sedimentary formations are found at depths in excess of 18,000 feet, containing rocks which date to Cambrian, Ordovician and Silurian time. Paleozoic rocks of these types, however, are rare and only found at extreme depths in the state. The major portion of the Florida Peninsula is underlain by more recent Cenozoic and Mesozoic sedimentaries. The oldest rock outcrop in the state is the Eocene Avon Park formation. Other limestones of Oligocene, Miocene and Pliocene age outcrop more frequently.

The dominant structural feature of the peninsula is the Ocala Arch. Upwarping of the Tertiary strata began prior to late Eocene time and continued through the Pliocene. Because of the present position of former Pleistocene shorelines, upwarping is believed to have stopped prior to the Pleistocene Epoch (Cooke, 1945).

Deformation of the Tertiary strata during the Ocala uplift has greatly influenced the formation and operation of the Floridan Aquifer. Ocala limestone which is the most important component of the aquifer system, is found 150 feet above sea level in the central part of the state. However, at Miami, 250 miles to the south, the formation is found at 1200 feet below sea level. Movement of groundwater through this formation and other parts of the aquifer has greatly influenced the physical and cultural patterns of present day Southern Florida. At more detailed discussion of the components and influence of the Floridan Aquifer will be found later in this chapter.

Geology of the Study Area

The Hillsborough River Basin is underlain by three major limestone formations of Miocene and Oligocene age. Figure 5 illustrates the spatial distribution of these formations in West Central Florida and lists them in descending chronological order. The oldest series found in the study area is Late Oligocene in age, represented by Suwannee limestone.

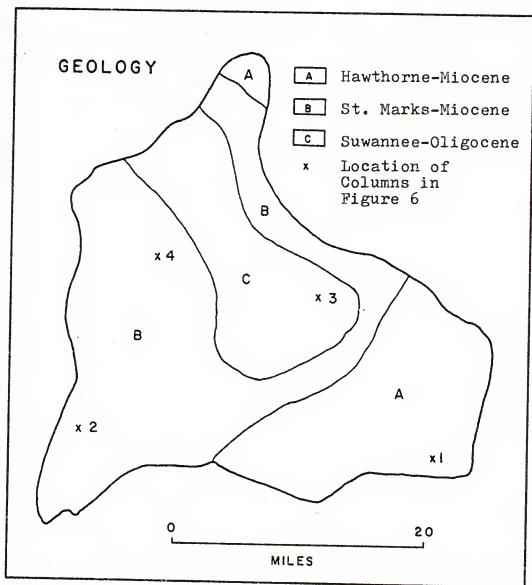


Figure 5

Nearly all of Pasco County is underlain by Suwannee limestone. Although this formation is covered in the north-eastern and southwestern portions of the county by the younger Hawthorne and Tampa limestones,* it continues to dominate the subsurface geology of the upper Hillsborough River Basin. This limestone is commonly yellow to cream in color and is characterized as a soft, granular, thin bedded rock which, in particular areas, is highly dolomitized. Cooke (1945) described the unaltered formation as 91 to 98 percent calcium carbonate (CaCO_3). However, surface exposures of this rock are usually heavily silicified, resulting in the occurrence of Suwannee flint rock. Suwannee limestone is a part of the principal artesian aquifer in the basin and provides an adequate supply of water for local use. There is significant utilization of this formation within the area. Suwannee limestone is used as a source of road metal and aggregate for concrete. Both are economically important to the region.

The northern tributaries of the Hillsborough River (Cypress Creek, New River and Trout Creek) are influenced by the St. Marks formation. This Early Miocene formation underlies the landscape of Northwest Hillsborough, North Pinellas and Southwest Pasco Counties. The limestone,

*According to the Florida Board of Conservation, Bureau of Geology, the Tampa Stage within the Miocene Series consists of the St. Marks and Chattahoochee formations. Therefore, for the purpose of this study, Tampa limestone will be equated with the St. Marks formation.

commonly referred to as Tampa limestone, appears as a sandy rock, usually light yellow in color. Cooke (1945) described its varying chemical composition as containing approximately 74 percent calcium carbonate (CaCO_3) and 24 percent silica (SiO_2).

Tampa limestone constitutes a major portion of the principal artesian system in this part of West Central Florida. This formation is of little use as a source of lime or aggregate agent when compared to the purer Suwannee or Ocala groups because of its considerable silica content. However, due to its sandy texture, the St. Marks formation is extremely porous and serves as a major source of fresh water for the area. Pinellas County and the City of St. Petersburg derive their entire source of fresh water from well fields which tap this formation.

The porosity of the Tampa limestone has resulted in a system of interior drainage within this portion of the study area. Comparison of the basin location map (Figure 1) with the local geologic map (Figure 5) show that surface water drainage is minimal within the northwestern limits of the Hillsborough Basin underlain by this formation. A further discussion of the effects of the St. Marks formation on the surface water hydrology of the region will be found later in this chapter.

The youngest formation in the study area is the Hawthorne. In addition to forming the bedrock complex of the southern tributaries of the Hillsborough (Blackwater,

Pemberton, and Flint Creeks), this formation also underlies the Alligator Creek subarea. According to the U.S. Geological Survey (Vernon and Puri, 1964), the beds of this formation are composed of phosphoric marine sands, clays and marls and may be described as a yellow sandy limestone. Although phosphate production from this series is important in portions of Hillsborough and Polk Counties, it is of less significance within the limits of the study area.

The numerous clay and marl impurities associated with this limestone have decreased the porosity and ground water yield of the Hawthorne formation. Because of these characteristics, surface water runoff from precipitation responds at a more rapid rate in this area than in portions of the basin underlain by the St. Marks and Suwannee formations.

In Hillsborough County, the Hawthorne is considered a shallow surface aquifer yielding a low quantity and quality of water. Although the formation is not a totally impervious layer, it does tend to hamper ground water movement to the underlying formations of the Floridan Aquifer. The relationship of the Hawthorne to other strata in the basin may be seen in Figure 6, along with other columnar sections selected in Hillsborough County. The locations of each of these stratigraphic sequences are shown in Figure 5.

Topography

C. W. Cooke (1939) described five topographic regions within the State of Florida (Figure 7). The Hillsborough

Figure 6: Columnar Sections - Hillsborough River Basin

Numbers within these columnar sections represent the following strata.

1. Hawthorne Limestone
2. Tampa Limestone
3. Suwannee Limestone
4. The Ocala Group
5. Avon Park Limestone
6. Lake City Limestone

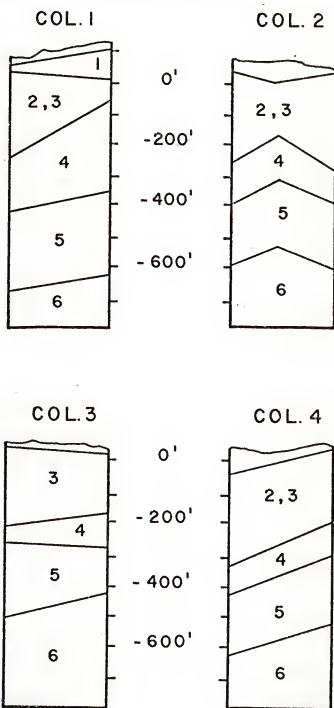


Figure 6

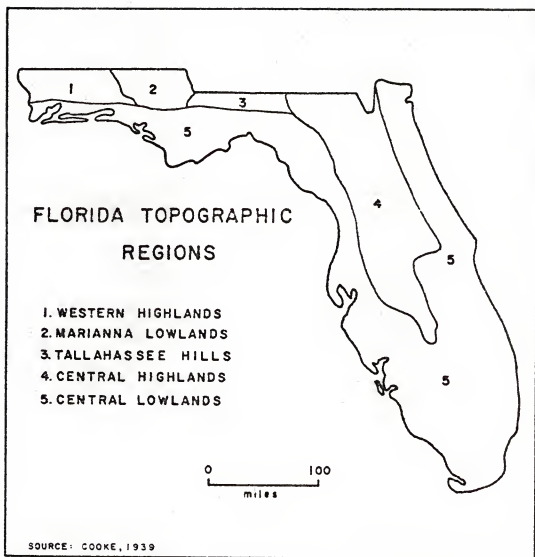


Figure 7

River rises in the southern portion of the Central Highlands and flows to the southwest across the Coastal Lowlands to Tampa Bay. The topography of the Central Highlands in this part of West Central Florida is dominated by the irregular rolling hills of the Brooksville Ridge. The Hillsborough breaches this ridge through its oldest and southernmost gap at Zephyrhills (White, 1970).

The division of these two topographic regions is generally accepted to be found at the 100 foot contour line. Near Tampa, the Coastal Lowlands extend inland for approximately forty miles. The landscape of the basin across this lowland plain is influenced by the presence of four marine terraces which were formed during Pleistocene fluctuations in the sea level. These terraces, as described by Cooke, are the Wicomico Terrace (100 feet), Penholoway Terrace (70 feet), Talbot Terrace (42 feet), and Pamlico Terrace (25 feet). The spatial extent of the Wicomico and Pamlico stands of sea level may be seen in Figure 8.

In addition to fluctuations in sea level, other elements have helped develop the character of Florida's topography. These are: 1) erosion by running water, 2) ground water solution, 3) coastal processes and 4) wind. Within the Hillsborough Basin, however, erosion by running water and ground water solution have been the most active agents shaping the landscape while coastal processes and wind have been more active outside of the study area.

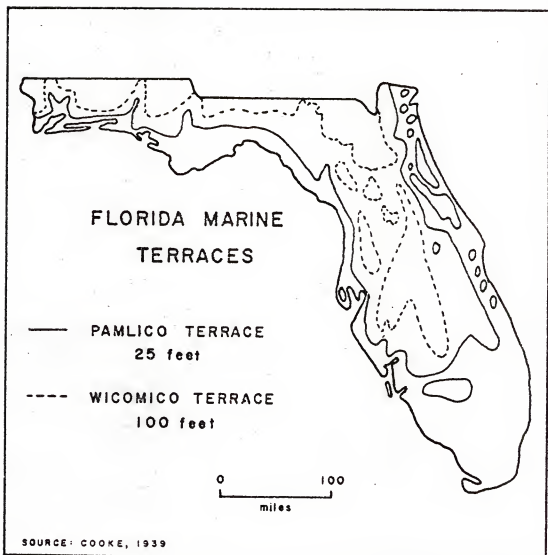


Figure 8

Because of the character of the soils and underlying bedrock, fluvial erosion has not been as dominant in Florida or the study area as might be expected in other similarly humid regions (Marcus, 1964). Local drainage patterns and textures within the Hillsborough River Basin exemplify this relationship. Comparison of the drainage textures of the southern tributaries with those of the northern tributaries and the northwestern portion of the basin, illustrates this relationship between fluvial erosion and bedrock porosity and permeability.

The landforms and topography in the vicinity of the trunk stream and major tributaries underlain by the Hawthorne formation are similar to Davis' "Old Age" erosional classification. Drainage divides within the area are difficult to locate and extensive floodplains are common to the landscape.

Removed from this region of fluvial topography is an area of interior drainage located in the northern and western parts of the basin. This area is underlain by the more porous Tampa and Suwannee formations and is characterized by a noticeable lack of extensive surface water drainage. Rather, the area is dotted with numerous sinkholes and lime-sink lakes found in conjunction with other features of subsidence and limestone solution.

There will be a further discussion of these topographic differences in the next section concerning physiographic division.

Physiographic Regions

In an explanation of the physical setting of the Hillsborough River Basin, the physiographic region serves as a base for a systematic method of studying the local characteristics and differences within the study area. The purpose of physiography as a science is explanation rather than pure physical description (Fenneman, 1938). For this reason, detailed analysis of the physical characteristics of the basin will lead to a better understanding of how man's past cultural activity has affected the area and, more important, of what his future influence may be. Before actual delineation and discussion of the physiographic divisions takes place, it seems appropriate to establish a usable regional definition.

The regional concept is used by geographers to study the spatial characteristics and interactions of places on the earth. In this respect, however, the study of place does not restrict the geographer to mere site and situation of specific localities. Rather, it allows him to study larger areas (regions) along with their internal structures and relationship to other regions.

Many regional definitions have been proposed, but with little success for universal acceptance. Because of the diversity of their discipline, geographers have different needs for establishing regional boundaries. For example, Fenneman's Great Plains Region differs considerably from the Great Plains delineated by Baker in 1923 as an

agricultural region (Broek and Webb, 1968). Thus, the formulation of a regional law containing specific criteria for all regions is impractical. Generically, there are as many types of regions as there are reasons for delimiting them. Although most regions may be classified as either formal or functional in nature (Hartshorne, 1959), the possibilities for further definition are numerous.

In a regional definition, specific criteria should be used to satisfy the requirements of the individual. Just as a cartographer uses different pen sizes for visual impact, the regional geographer should use different regional criteria to establish his specific regions. If in geography, the region must be universally defined, the definition should be flexible enough so as to be useful to geographers. Broek and Webb suggested such a definition when they said, "A region, then, is a part of the earth that is alike in specific criteria chosen to delimit it from other regions " (Broek and Webb, 1968, pp. 14, 16). In this way three physiographic regions have been established in the Hillsborough River Basin.

The study area, as defined by the U.S. Geological Survey, includes the land area drained both internally and externally by the Hillsborough River System. Although the area is ultimately drained by the main stream, differences in drainage characteristics have led to the formulation of three separate physiographic subregions within the basin(Figure 9). These areas include; the Limesink

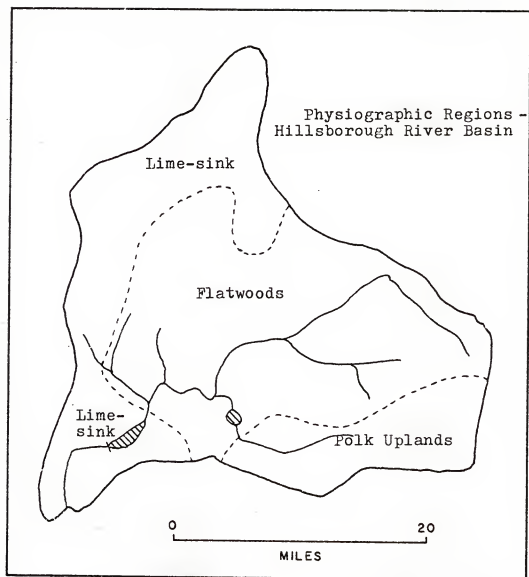


Figure 9

Region, the Flatwoods and the Polk Uplands. Each of these physical divisions are significantly different from each other in topography and local drainage to justify separation. A general comparison of the physiographic characteristics of each is found in Table 5.

The Lime-sink Region

The lime-sink region of the Hillsborough River Basin is characterized by predominantly well-drained soils containing relatively few extensive surface streams. The area is dotted with numerous small sinkhole lakes which serve as reservoirs for the surface water of the area. Most of this physiographic division is typically karst in appearance.

This portion of the river basin is underlain by the Tampa and Suwannee formations. The combination of a relatively porous underpinning covered by a layer of very porous sand has resulted in wide-ranged limestone solution in the region. Although relief is suitable to induce runoff from precipitation throughout most of the area, the porosity of the surface material and substratum have limited the development of an extensive surface water drainage system. Most surface drainage in this division consists of small, sometimes intermittent streams which flow into many of the small karst lakes.

One such stream is Curiosity Creek located in the southwestern portion of the basin. This stream follows

Table 5: General Characteristics of Physiographic Regions

Region	Bedrock	Relief	Dominant Drainage	Soil Drainage
Lime-Sink	Tampa and Suwannee Limestones	Little to Moderate	Interior	Good
Flatwoods	Tampa and Suwannee Limestones with underlying pan; Hawthorne Lime-stone	Little	Surface	Poor to Fair
Polk Uplands	Hawthorne and Bone Valley* formations	Moderate to Hilly	Surface	Fair to Good

*The Bone Valley formation is found throughout much of the Polk Uplands described by White (1970), but is almost totally absent in the study area.

a course of a few miles connecting several sinkhole ponds and ultimately drains into Blue Sink near North Tampa. From this sink, water from Curiosity Creek flows underground until it reappears at the surface at Sulphur Springs and thereby becomes a fresh-water source to the lower Hillsborough River. Examples of this type of drainage are not uncommon in the lime-sink region of the river basin.

The Flatwoods

The Flatwoods region is the most extensive of the three physical divisions in the Hillsborough River Basin. Most of the main river and its tributaries flow through this area, shaping its landscape. Within the low broad interfluves, surface drainage is relatively poor resulting in numerous swamp and marsh areas throughout. Although the higher portions of the Flatwoods are better drained, the occurrence of low lying areas with standing water is more frequent here than in the other physiographic regions.

This region is underlain by the clayey, marl sediments of the Hawthorne formation and the porous limestones of the Tampa and Suwannee groups. The sedimentaries of the Hawthorne are less porous and less susceptible to subsurface solution than the purer Tampa and Suwannee limestones. Although examples of subsidence are found in the Flatwoods, they are more subtle than those found in the lime-sink region. The most widespread evidence of solution in this area is found with relation to the numerous circular stands

of cypress which dot the higher grasslands of the region. Swamps and poorly drained bottom lands characterize most of the river's course.

Although sands compose much of the surficial coverage of the Flatwoods, the drainage is fairly poor. Many areas of well drained grasslands are found, but they are intermixed with numerous low lying poorly drained patches. Primarily, the poor drainage within this region may be partially explained by the relationship between fairly low elevation and the presence of a high water table. Also, the soils found above the porous Tampa and Suwannee limestones contain a relatively impervious organic pan which decreases the rate and extent of percolation (U.S.D.A., 1958). Therefore, the combination of a high regional water table, low relief and elevation, and the presence of an underlying aquiclude results in the typically poor soil drainage of much of the Flatwoods.

The Polk Uplands

Only a small portion of the Polk Uplands described by White (1970) are found in the Hillsborough River Basin. Although the Bone Valley formation dominates the underlying geology of this physiographic region outside of the study area, it is almost totally absent within the limits of the Hillsborough Basin. Here, similar to the Flatwoods, the relatively impervious clay-marls of the Hawthorne formation are found beneath a surface covering of sand or alluvial soils.

Although both regions are underlain by the same formation, the greater relief of the Central Highlands has increased surface water runoff and soil drainage in the Polk Uplands over that of the Flatwoods. Consequently, there is less evidence of solution of the limestones in the uplands. Solution of the Hawthorne in each of these regions, however, is less extensive than solution in the lime-sink area.

Climate

Traditionally, the study of climate has been concerned with the comparison of average temperature and precipitation relationships. At this level, the Koeppen Climatic Classification is suitable for worldwide, continental and large national comparisons. However, its limitations in the microclimatological study of the Hillsborough River Basin are numerous.

Analysis of the climatological data listed in Table 6 results in the subsequent classification of Tampa, Florida as a Cfa climate in the Koeppen system. Translation of these symbols (Table 7) indicates the general range of temperature and distribution of annual rainfall within the region, but reveals little if any information concerning evapotranspiration or precipitation effectiveness. Study of these latter components of climate is critical for research on the relationship between precipitation, urbanization and runoff.

Table 7: Translation of Koeppen Cfa Climatic Classification for Tampa, Florida

Symbol	Requirements for Classification
C	Average Temperature 1) the warmest month is greater than 50°F 2) the coldest month is greater than 32°F but less than 64.4°F
f	Precipitation not meeting conditions of summer or winter drought (s or w classification respectively)
a	Average temperature of warmest summer month is greater than 71.6°F

Source: Critchfield, 1966

Table 8: Comparison of Koeppen and Thornthwaite Climatic Types

	Wet	Wet & Dry	Dry	
	AF	Aw,Am, BSH	BWh	Koeppen
Tropical	-----			
	AA'r,BA'r CA'r	BA'w,CA'w DA'w	CA'd,DA'd EA'd	Thornthwaite
	Cf,Df	Cs,Cw, Dw,BSk	BWk	Koeppen
Mid-latitude	-----			
	AB'r,BC'r AC'r,CB'r BB'r,CC'r	BB's,CC's BB'w,DB's BC's,DA'w CB's,DB'w CB'w	CB'd,DC'd CC'd,EB'd DB'd,EC'd	Thornthwaite
		ET	EF	Koeppen
Polar	-----			
		E	F	Thornthwaite

Source: Hidore, 1969

Most climatic classifications serve as systematic methods of evaluating particular climatic data. The system which best satisfies the requirements of this study was developed by C. W. Thornthwaite in 1931 with further revision in 1948. A comparison of the Koeppen and Thornthwaite Climatic Types may be found in Table 8. Before Thornthwaite's climatic formulas are applied to the Hillsborough River Basin, it is necessary to discuss the characteristics of temperature and precipitation in the study area.

Temperature and Precipitation

There is little regional variance in average temperature throughout most of the study area. According to Bradley (1972), average annual temperatures in the basin vary about 0.3°F with Tampa and Plant City reporting 72.2°F and 71.9°F respectively. Mean monthly temperatures range from 80° to 82° in the summer and 61° to 66° in the winter, giving the region an average reading of about 72°F.

The greatest discrepancies within the Tampa Bay region exist between coastal and inland areas and reflect the moderating effects of the Gulf of Mexico upon coastal locations. However, within the inland river basin, the smallest diurnal ranges are related to slope and lake proximity. This fact greatly influences citrus production, but has little effect on the monthly or annual average temperature and thus is not incorporated in Koeppen's System.

Although applications of Koeppen formulas and the 1931 Thornthwaite Classification indicate an equitable annual distribution of rainfall in the Tampa Bay region, there is a notable difference between the relatively dry winters and wet summers. These seasonal fluctuations, however, are not great enough to warrant a Koeppen Cwa Classification for the area.

Unlike the stable climatic component of temperature, precipitation varies considerably on the local scale throughout most of the Hillsborough Basin. This fact may be explained by the numerous localized thunderstorms which are common to much of central Florida during the summer. Furthermore, land and sea breezes contribute to a thunderstorm pattern which plays a part in local irregularities in precipitation. For this reason, precipitation data from one recording gauge does not present an accurate account of the rainfall characteristics of the region.

An example of this may be seen from the comparison of daily precipitation records of two fire towers in the river basin. The first of these is Hamner Tower (Station 1, Figure 10) located in the western portion of the study area. The second is the Hillsborough River State Park Tower (Station 3, Figure 10) which is located approximately fifteen miles east of Hamner. On July 8, 1959, records indicate that 2.4 inches of precipitation from a thunderstorm fell at Station 1. However, no measurable rainfall was recorded at the state park. It is interesting that the

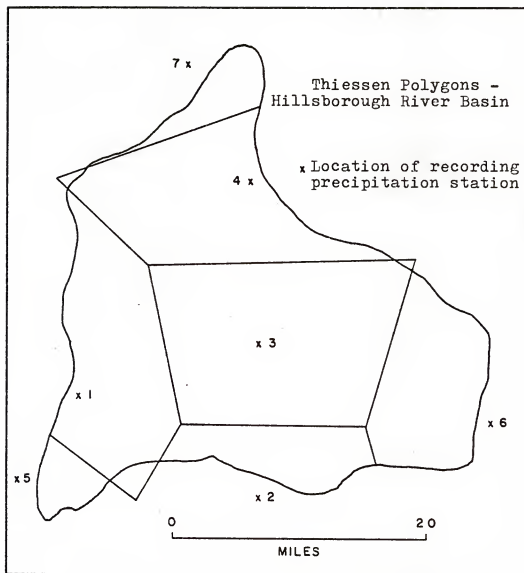


Figure 10

monthly record for July, 1959 only varied 0.17 inches between the stations (Hamner, 11.15"; Park, 10.98"). For the year, total annual precipitation varied 26.29 inches (Hamner, 107.6"; Park, 81.31"). Although 1959 was a considerably wet year for Florida, Hamner Tower more than doubled the 51.57 inches considered normal for the Tampa area.

With variable precipitation of this magnitude, it is difficult to establish reliable mean values for rainfall over the basin area. In order to obtain valid figures for average monthly and annual precipitation, three stations were selected for analysis within the study area. When available, fire tower data was selected over urban or airport recordings in order to achieve a more natural situation for measuring rainfall. Use of a simple arithmetic mean from these stations would improve the validity of the statistic over that of the mean Tampa value. However, the size of the available sample was not sufficient. Although the three stations were scattered across the study area, additional data were necessary to overcome the precipitation variability factor.

Four other stations were selected on the periphery of the watershed (Table 9, Figure 10). Again, a simple arithmetic mean could be computed from the data of these seven stations. However, this method of establishing mean precipitation values would give equal weight to each of the reporting stations, regardless of their position and total

Table 9: Precipitation Data for Seven Recording Stations - Hillsborough River Basin

Sta.#	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
1	3.38	4.53	5.94	2.20	3.27	7.93	12.14	12.00	7.53	3.07	1.77	2.81	66.94
2	3.52	3.72	4.77	2.09	4.06	10.10	9.08	9.53	6.58	3.14	1.44	2.12	60.11
3	3.36	4.39	5.40	2.04	4.45	10.02	10.24	11.21	8.00	2.88	1.84	2.72	66.26
4	2.30	2.90	4.10	3.20	4.20	8.30	8.80	7.90	7.10	3.40	2.00	2.30	56.30
5	2.13	2.84	3.75	2.84	2.85	7.28	8.62	8.24	6.89	2.78	1.46	1.89	51.57
6	2.20	2.60	3.90	3.00	4.30	7.30	8.00	7.30	6.30	2.70	1.70	2.00	51.20
7	2.40	2.90	4.00	3.30	3.90	7.80	9.70	8.60	7.00	3.30	2.10	2.60	57.50

Sources: Stations 1-3: Fire Tower Records provided by Dr. Dewey Stowers, U.S.F.

Station 5: Bradley, 1972

Stations 4,6,7: Florida Board of Conservation, 1966

Note: It should be noted at this point that the fire tower statistics appear to be significantly higher than the other stations recorded. This fact may be partially attributed to the period of record used for computation of averages. Fire tower data was calculated over an eleven year period of record (1958-1968) while values for the other stations used a fifty year period. Although tower data increased the ultimate mean value considerably, it should be remembered that it was recorded during the period of record for this study. For this reason, its inclusion and influence are extremely important.

influence on the basin. A method developed by A. H. Thiessen in 1911 (Wisler and Brater, 1967) was used in order to compute the most representative precipitation averages for the study area.

The Thiessen polygons (Figure 10) are constructed so that the area within each figure is closer to the enclosed station than to any of the surrounding stations. Therefore, figures from each recording gauge are considered to be the most representative of that area's precipitation. The basin average is calculated according to the formula

$$P_b = \frac{P_1 A_1 + P_2 A_2 + \dots + P_n A_n}{T}$$

where P_1 is equal to the average precipitation of station 1 (etc.), A_1 is equal to the area of the respective polygon and T is equal to the total basin area. By using this method, the resulting basin average (P_b) is weighted proportionally to the area represented by each station.

The areas of the Thiessen polygons listed in Table 10 were determined by use of a simple dot grid. These values along with the mean monthly total for each station were used to determine the monthly Thiessen mean. These values were then totaled to determine the average annual precipitation for the basin.

Table 11 lists the several possible sets of precipitation data available for use. Inspection of this data reveals a maximum difference of 11.78 inches between these averages.

Table 10: Areas of Thiessen Polygons

Station #	Name	Dot Grid Area	% of Total
1.	Hamner Fire Tower	35	15.4
2.	Valrico Fire Tower	20	8.8
3.	State Park Tower	69	30.4
4.	St. Leo	52	22.9
5.	Tampa	7	3.1
6.	Lakeland	35	15.4
7.	Brooksville	9	4.0
	Total	227	100.0

This significant variance mandates separation of one set of data which appears to be most representative of the basin's actual mean precipitation. Because the Thiessen method provides a proportional average of numerous stations, it is considered the most accurate representation of precipitation in the Hillsborough River Basin. Therefore, this set of climatological data accompanied by mean temperature values for Tampa will be used in application of the Thornthwaite models.

Climate According to Thornthwaite

In an article published in the Geographic Review of Oct ., 1931, C. Warren Thornthwaite introduced a "new" system for analyzing the climates of North America. This system was expanded in 1933 as a basic world wide classification of climate. Similar to Koeppen's previous system,

Table 11: Comparison of Mean Precipitation Values

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Tampa	2.13	2.84	3.75	2.84	2.85	7.28	8.62	8.24	6.89	2.78	1.46	1.89	51.57
Basin Mean	3.01	3.94	5.15	2.48	4.12	8.75	10.39	10.37	7.54	3.12	1.87	2.61	63.35
Arith. Mean Sta. 1-7	2.76	3.41	4.55	2.67	3.93	8.39	9.51	9.25	7.06	3.04	1.76	2.35	58.68
Thiessen Mean	2.88	3.63	4.79	2.56	4.15	8.72	9.73	9.61	7.26	3.04	1.81	2.44	60.62

Thornthwaite established climatic formulas, derived climatic boundaries through empirical analysis of vegetation, soil and drainage types and thus, developed a tri-symbol system for climatic classification (Critchfield, 1966). His primary deviation from the Koeppen system was found in the quantitative derivation of two new climatic components; precipitation effectiveness and temperature efficiency. The original 1931 classification is summarized in Table 12.

Thornthwaite's reasoning for a new system evolved from the need of a more detailed comparative analysis of the temperature-precipitation relationship than the Koeppen System supplied. Koeppen suggested the idea of precipitation effectiveness by differentiating the seasonal distribution of rainfall (f, s, and w). Thornthwaite's classification, however, established quantitative limits for a P-E Index which more clearly described effective precipitation with relation to temperature.

According to the 1931 Thornthwaite boundaries, the Hillsborough River Basin is classified as a BB'r to CB'r climatic type. Translation of these symbols describes the area as a humid to subhumid mesothermal climate with no drought period. Simple comparison of the Koeppen and Thornthwaite translations reveals little difference in description. However, recognition of the P-E and T-E Indices with the latter classification, increases its value for analysis of the area's water budget.

Table 12: 1931 Thornthwaite Classification of Climate

Precipitation Effectiveness

P-E Index $I = \text{sum of twelve monthly values of } 115(P/T - 10)^{10/9}$ where P = mean monthly precipitation in inches and T = mean monthly temperature in °F.

<u>Humidity Province</u>	<u>Vegetation</u>	<u>P-E Index</u>
A Wet	Rain Forest	128 and above
B Humid	Forest	64 to 127
C Subhumid	Grassland	32 to 63
D Semiarid	Steppe	16 to 31
E Arid	Desert	less than 16

Temperature Efficiency

T-E Index $I' = \text{sum of twelve monthly values of } T - 32/4$
where T = mean monthly temperature in °F.

<u>Temperature Province</u>	<u>T-E Index</u>
A' Tropical	128 and above
B' Mesothermal	64 to 127
C' Microthermal	32 to 63
D' Taiga	16 to 31
E' Tundra	1 to 15
F' Frost	0

Seasonal Distribution of Precipitation

r	Rainfall adequate in all seasons
s	Rainfall deficient in summer
w	Rainfall deficient in winter
d	Rainfall deficient in all seasons

Source: Thornthwaite, 1931

In 1948, Thornthwaite modified this 1931 system significantly. cursory inspection of the revised classification merely reveals the addition of a fourth criterion and a finer breakdown of precipitation effectiveness and thermal efficiency limits. However, a more detailed comparison of the two, shows that the modified climatic divisions are not distinguished by precipitation and temperature data alone. Rather, the component of potential evapotranspiration has been added. With this added dimension, the role of vegetation in climatic evaluation was changed. In the 1931 system, Koeppen's consideration of vegetation as an expression of climate was used, whereas, in the revised classification, vegetation was considered a mechanism of moisture transfer from the soil to the atmosphere (Thornthwaite, 1948).

The importance of evapotranspiration as a process of water transfer in the hydrologic cycle has been recognized by geographers and hydrologists. Potential evapotranspiration is the maximum amount of water possibly transferred from a given region over a particular period of time. It is a function of temperature, number of daylight hours, vegetation, and soil characteristics. Consideration of this climatic component is necessary for the study of the microclimatology and water balance of the Hillsborough River Basin because of its influence on atmospheric moisture and subsurface water retention.

Potential evapotranspiration may be considered the amount of water necessary to satisfy the requirements of temperature related evaporation, and vegetation related transpiration within a particular area. When this water need is satisfied by local precipitation and soil moisture supply, potential evapotranspiration will equal actual evapotranspiration for the region. When available water from these two sources is in excess of water demand, there will be a water surplus to runoff or recharge the ground water table. However, when local need surpasses local supply, there is a water deficit for the region and drought conditions exist.

The importance of soil moisture is evident when considering the occurrence of water surplus or water deficiency. The maximum amount of water possibly stored in the soil at a given time (soil moisture capacity) and available for vegetative use is dependent upon two factors. These are; 1) porosity of the soil and 2) the average depth of the vegetative root zone. Thornthwaite and Mather (1957) developed a set of tables from which maximum soil moisture storage can be determined for various vegetation and soil combinations. Since neither soil nor vegetation are uniform across the watershed, no single association could be used to determine the soil moisture capacity of the study area. Therefore several combinations were averaged to determine a mean storage capacity of five inches for

the Hillsborough River Basin. This figure represents an average for the region which will be used in determining the moisture characteristics of the study area.

Table 13 lists the data necessary to implement the revised Thornthwaite system of climatic classification. The basic temperature and precipitation statistics used were explained in the previous section. Potential evapotranspiration figures were calculated according to the method described by Thornthwaite in his 1948 modification. Computation of these figures along with the necessary graphs and tables may be found in Appendix I.

Calculation of the moisture data for the classification of climate began in the March column. This was selected as the starting point because of the sufficiently wet period that preceded it. During March, soil moisture storage was assumed to be at its maximum of five inches. For that month, precipitation exceeded the water need and soil moisture was at full capacity. Therefore, there was a water surplus of 2.36 inches for the month. Similar inspections were made for the remainder of the year. Whenever precipitation was less than potential evapotranspiration, there was a net loss recorded in the storage change row. This amount was then subtracted from soil moisture storage figure and the remainder was entered as available soil moisture for the following month. Since there was no period when water need was not satisfied, there was no water

Table 13: Monthly Water Balance Table - Hillsborough River Basin

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Temperature °F	61.2	62.7	66.0	71.4	76.8	80.6	81.6	82.0	80.5	74.7	66.8	62.3	72.20
Precipitation (In)	2.88	3.63	4.79	2.56	4.15	8.72	9.73	9.61	7.26	3.04	1.81	2.44	60.62"
I = sum of i's	5.94	6.41	7.48	9.35	11.36	12.85	13.25	13.41	12.81	10.56	7.75	6.22	117.39
Unadjusted PE	1.46	1.77	2.36	3.38	4.72	5.50	5.69	5.76	5.48	4.09	2.52	1.69	
Adjusted PE	1.33	1.56	2.43	3.62	5.52	6.38	6.71	6.51	5.64	4.01	2.27	1.52	47.50"
Precip. - PE	1.55	2.07	2.36	-1.06	-1.37	2.34	3.02	3.10	1.62	-0.97	-0.46	0.92	
Acc.Pot.Wat. Loss				-1.06	-2.43					-3.4	-3.86		-3.86
Storage	4.49	5.00	5.00	5.00	3.94	2.57	4.91	5.00	5.00	5.00	4.03	3.57	
Storage Change	+0.51			-1.06	-1.37	+2.34	+0.09			-0.97	-0.46	+0.92	
Actual Evapotrans.	1.33	1.56	2.43	3.62	5.52	6.38	6.71	6.51	5.64	4.01	2.27	1.52	
Deficit													
Surplus	1.04	2.07	2.36				2.93	3.10	1.62				13.12
Runoff	0.65	1.36	1.86	0.93	0.47	0.23	1.58	2.34	1.98	0.99	0.49	0.24	13.12
G'water Storage	1.05	2.34	2.95	0.74	0.19	0.05	3.06	3.87	2.59	0.65	0.16	0.04	
Base Flow	0.53	1.17	1.48	0.37	0.10	0.23	1.53	1.93	1.29	0.33	0.08	0.02	
Surface Runoff	0.12	0.19	0.38	0.56	0.37	0.00	0.05	0.41	0.69	0.66	0.41	0.22	

deficiency for the year. Thus, actual evapotranspiration always equaled the potential figure.

Inspection of Table 13 and Figure 11 points out two periods when water from the soil moisture reservoir is necessary to prevent drought conditions. Maximum water depletion from this source occurs in May with a total loss of 2.43 inches through evapotranspiration. Using these figures, Thornthwaite's formulas will be applied to determine the climatic classification of the study area.

The first component of the classification is that of the Moisture Index (I_m). It is determined by the relationship between the relative humidity and aridity of the overall climatic situation. Thornthwaite first established the indices of humidity and aridity as percentages. Their formulas are:

$$I_h = 100s/n \text{ and } I_a = 100d/n$$

where I_h and I_a are the indices of humidity and aridity respectively, s is the water surplus, d is the water deficiency and n is water need (potential evapotranspiration). It is known that water surpluses and deficiencies occur in many areas during different parts of the year. To some extent, a water surplus in one season can partially compensate for or decrease the overall effect of a water deficit during another season through the recharge of soil moisture. Therefore, in the moisture index, the index of humidity has greater weight than the index of aridity.

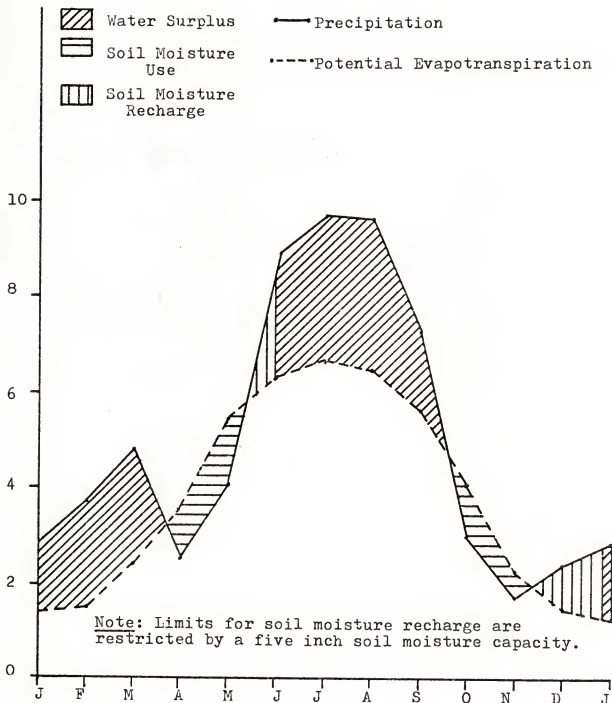


Figure 11: Thornthwaite Comparison of Potential Evapotranspiration and Precipitation - Hillsborough River Basin

Thornthwaite calculated that in the total moisture index, the Index of Aridity had only six-tenths the impact of the Index of Humidity. Therefore, the Moisture Index was stated as follows:

$$I_m = \frac{100s - 60d}{n}$$

When the appropriate values for the study area are substituted in this formula, the results are:

$$I_m = \frac{100 (13.12) - 60 (0)}{47.5}$$

$$I_m = 1312 / 47.5$$

$$I_m = 27.62$$

When compared to the limits listed in Table 14, the Hillsborough River Basin is said to be a B_1 (humid) climatic type.

The second component of the system is the Index of Thermal Efficiency. Because potential evapotranspiration (PE) expresses precipitation effectiveness with relationship to temperature and length of day, Thornthwaite believed that this figure would best represent the climatic characteristic of thermal efficiency. The potential evapotranspiration calculated for the study area is 47.5 inches per year. When compared to the limits established in Table 15, the thermal efficiency of the region is classified as an A' (Megathermal) climate.

Table 14: Limits of Thornthwaite's Moisture Index

Climatic Type		Moisture Index
A	Perhumid	100 and above
B ₄	Humid	80 to 100
B ₃	Humid	60 to 80
B ₂	Humid	40 to 60
B ₁	Humid	20 to 40
C ₂	Moist subhumid	0 to 20
C ₁	Dry subhumid	-20 to 0
D	Semiarid	-40 to -20
E	Arid	-60 to -40

Source: Thornthwaite, 1948

Table 15: Limits of Thornthwaite's Index of Thermal Efficiency

TE Index (PE)		Climatic Type	
cm.	in.		
		E'	Frost
14.2	5.61	D'	
28.5	11.22	C'	
42.7	16.83	C' ₁	Microthermal
57.0	22.44	C' ₂	
71.2	28.05	B' ₁	
85.5	33.66	B' ₂	Mesothermal
99.7	39.27	B' ₃	
114.0	44.88	B' ₄	
		A'	Megathermal

Source: Thornthwaite, 1948

Thorntwaite's third criterion is that of seasonal variation of effective moisture. Although this component seems to have appeared in his former classification, present derivation of this climatic boundary is based on the indices of humidity and aridity which are functions of water need. In moist climates, the period and magnitude of I_a determine this segment of the classification. Because the study area has no seasonal water deficiency, $I_a = 0$ and the symbol r results (Table 16).

Thorntwaite's last climatic component in his 1948 classification concerns the summer concentration of thermal efficiency. The symbol representing this characteristic is determined by calculating the percentage of the total annual potential evapotranspiration that occurs in the summer quarter. Values listed in Table 17 represent the boundaries established for each of these climatic symbols. The total PE for the study area is 47.5 inches. Of this total, 25.24 inches or 53.1 percent occurs in the summer. Thus, the final symbol for the regional classification is b'_3 .

According to Thorntwaite's 1948 classification, the Hillsborough River Basin is established as a $B_1A'rb'_3$ climatic type. Mere verbal translation of these symbols is less significant to the hydrologist than the quantitative limits represented by each. Further use and explanation of the data listed in Table 13 will take place in the discussion of the regional water budget later in this chapter.

Table 16: Seasonal Variation of Effective Moisture

Moist Climates (A, B, C ₂)	Aridity Index
r little or no water deficiency	0 - 16.7
s moderate summer water deficiency	16.7 - 33.3
w moderate winter water deficiency	16.7 - 33.3
s ₂ large summer water deficiency	33.3 +
w ₂ large winter water deficiency	33.3+
Dry Climates (C ₁ , D, E)	Humidity Index
d little or no water surplus	0 - 10
s moderate winter water surplus	10 - 20
w moderate summer water surplus	10 - 20
s ₂ large winter water surplus	20 +
w ₂ large summer water surplus	20 +

Source: Thornthwaite, 1948

Vegetation and Soils

The previous discussion of Thornthwaite's climatic classification and its methods of determining moisture data point out the important relationships between soil, vegetation and the hydrologic characteristics of the Hillsborough River Basin. The interrelationships of precipitation, storage, ground water recharge, and runoff have already been mentioned. However, it should be noted once more, that soil moisture capacity is solely determined by the soil-vegetation association present in the region (Thornthwaite and Mather, 1957). It is beyond the scope

Table 17: Limits for Summer Concentration of Thermal Efficiency Classification

Total Potential Evapotranspiration		Summer Concentration Percentage	Summer Concentration Type
Ins.	Cms.		
44.88	114.0	48.0	a'
39.27	99.7	51.9	b' ₄
33.66	85.5	56.3	b' ₃
28.05	71.2	61.6	b' ₂
22.44	57.0	68.0	b' ₁
16.83	42.7	76.3	c' ₂
11.22	28.5	88.0	c' ₁
5.61	14.2		d'

Source: Thornthwaite, 1948

of this study to discuss at great length the numerous botanical and pedologic characteristics of the study area. Rather, a general description of the vegetative and soil types will be given so as to clarify the soil moisture relationships and illustrate the overall features of the landscape.

Of the thirteen native vegetation types listed by Davis, three are present in the Hillsborough River Basin (Marcus, 1964). These are: 1) Pine Flatwoods, 2) Upland Pine and Scrub Oak Open Forests, and 3) Swamp Forests.

Pine Flatwoods

The Pine Flatwoods cover a major portion of the watershed. The name and distribution of this vegetation

type coincide with that of the Flatwoods physiographic region established previously in this chapter. This similarity in terms, however, should not confuse the reader as to the validity of the Flatwoods physiographic division. Rather, the term flatwoods refers not only to a vegetative type, but also to an area of particular soil, topography, and drainage type; the specific criteria used for delineation and separation of the physical area.

The vegetative region resembles an open pine woodland with many varieties of short grasses and palmettoes acting as ground cover. On the periphery of these forests, prairies of saw-palmettoes, short grasses and widely scattered longleaf pines are not unusual. Upon initial observation, the observer may mistake this association for a savannah type vegetation. However, as Davis (1943) pointed out, this comparison is incorrect because tall grasses dominate the vegetation of the tropical savannah.

In addition to open forests and palmetto prairies, there are many areas of poorly drained sands which support intermixed stands of bald cypress, water oak and hickory, red maple and cabbage palm. Throughout much of the study area covered by this thick forest, island hammocks of deciduous trees are common (Marcus, 1964).

Today, man has significantly changed the character of the natural vegetation of the flatwoods. Within the study area, many stands of pine have been completely removed for lumber and saw-palmetto prairies have been replaced

by pastures. This fact was considered when the soil moisture capacity figure was established for the basin.

Upland Pine and Scrub Oak Forests

These forests are naturally found within the Central Highlands and Lime-sink regions of the Hillsborough River Basin, associated with well to moderately well drained sands. The high pine forests are usually open stands of long-leaf pine intermixed with Turkey and Blue-jack Oaks. The normal ground cover in these areas consists of short grasses.

The scrub forest is dominated by the presence of several types of scrub oaks. Unlike the upland pine areas, this forest association consists of many low trees and shrubs intermixed with sand pines. Because of the thick tree cover, few grasses are found within this type of forest.

These forests are native to the Polk Uplands and Lime-sink physiographic regions of the study area. Today, much of the land covered by these forests is planted in citrus. The well drained characteristics of the associated soils and rolling topography make these areas ideal for citrus production. When calculating the soil moisture capacity for the study area, the Thornthwaite combination of "orchards on fine sand" was used to represent this area.

Swamp Forests

The third and least extensive type of vegetation found in the Hillsborough River Basin is swamp forest land. For

the most part, these forests are restricted to the poorly drained bottom lands found lining the course of the main river and major tributaries. These dense forests are mostly composed of several varieties of water oaks, red maple, cabbage palm and bald cypress. Because these areas are under water for much of the year, there has been little modification to their natural distribution. Table 18 illustrates the vegetation-soil associations found in the study area.

Soils

According to the U.S. Department of Agriculture (1958), there are four broad classes of soils present in the Hillsborough River Basin. These are: 1) Somewhat poorly drained sands with organic pan (Leon and Immokalee), 2) Bottom lands, swamps and ponds (undifferentiated), 3) Somewhat poorly drained sands over calcareous substratum (Ruskin, Sunniland and Adamsville), and 4) Well drained deep sands (Blanton, Lakeland and Eustis). The general description of the soil profiles for each soil type may be found in Table 19.

The soils of the flatwoods predominantly consist of those types listed in the first three classifications. Because of the water content and dense forest cover of the bottom land and swamp soils, detailed classification of these types has been difficult. For this reason, description of their profiles is not included in Table 19.

Table 18: Associated Vegetation and Soil Types - Hillsborough River Basin

General Type of Vegetation	Soil Types Generally Associated with this Type of Vegetation
1. Pine flatwoods with saw-palmetto and wire grasses common	1. Mostly ground water podzols as Leon and Immokalee fine sand
2. Scrub vegetation composed of sand pine, scrub oaks and sam-palmetto with few grasses	2. Characteristically deep, dry well drained sands such as Eustis, Lakeland, St. Lucie and Lakewood fine sands
3. Sandhill or high pine forests with oaks common. Some with scrubby tree growth, grasses and saw-palmetto	3. Blanton fine sand and in adjacent areas Norfolk fine sand, all well drained
4. Swamps dominated by cypress trees and cypress heads	4. Plummer fine sands and other unclassified soils (alluvial bottom land and swamp soils)

Source: Davis, 1943

The better drainage of the Lime-sink and Polk Uplands regions is partially explained by soil type. Well drained deep sands of the Blanton, Lakeland, and Eustis varieties dominate the character of the lime-sink area. Patches of poorly drained alluvial soil can be found in the region, but their occurrence is relatively rare when compared to that of the well drained sands.

The soils of the Polk Uplands are similar to those of the flatwoods. However, the increased elevations and relief associated with a somewhat lower water table has resulted

Table 19: Description of Soil Profiles - Hillsborough River Basin

Soil Type	Depth (In.)	Description
Leon fine sand	0-5	Dark gray nearly loose fine sand salt-and-pepper appearance due to small amount of organic matter.
	5-20	Light gray loose fine sand.
	20-24	Very dark grayish-brown fine sand; cemented with organic matter.
	24-30	Dark brown fine sand, weakly cemented.
	30-42+	Yellowish-brown loose fine sand in upper parts grading to lighter colors with depth.
Immokalee fine sand	0-6	Dark gray loose fine sand with salt-and-pepper appearance.
	6-12	Gray loose fine sand.
	12-32	Light gray loose fine sand with few light brownish gray spots.
	32-38	Very dark brown fine sand with slightly cemented organic pan.
	38-42+	Dark grayish brown loose fine sand grading lighter with depth.
Ruskin fine sand	0-6	Dark gray nearly loose fine sand with small to moderate amount of organic material.
	6-24	Light gray loose fine sand.
	24-36	Brownish-yellow fine sandy clay loam mottled with light gray.
	36-42+	White and pale yellow shell marl.
Sunniland fine sand	0-4	Dark gray nearly loose fine sand with small amount of organic matter, strongly acid.
	4-20	light-gray loose fine sand with yellow streaks in lower part, strongly acid.
	20-40	Mottled yellowish-brown strong brown to light gray fine sandy clay to fine sandy clay loam, strongly acid to neutral to mild alkaline with depth.

Table 19 - Continued

Soil Type	Depth (In.)	Description
Adamsville fine sand	20-40	Mottled yellowish-brown strong-brown to light gray fine sandy clay or fine sandy clay loam, strongly acid to neutral to mild alkaline with depth.
	40-48+	White marl, sandy clay to sandy clay loam texture, few lime concretions.
	0-4	Dark gray to gray loose fine sand.
	4-12	Light gray loose fine sand.
	12-24	Light yellowish-brown loose fine sand.
Blanton fine sand	24-34	Yellowish-brown loose fine sand.
	34-42+	Brownish-yellow loose fine sand.
	0-6	Dark gray to gray nearly loose fine sand.
	6-18	Grayish-brown to light brownish-gray loose fine sand.
	18-42+	Very pale brown or light gray loose fine sand, splotched, with pale yellow or yellow.
Lakeland fine sand	0-5	Dark gray loose fine sand; low in organic matter.
	5-12	Grayish-brown loose fine sand.
	12-30	Yellowish-brown loose fine sand.
	30-48+	Brownish-yellow loose fine sand.
Eustis fine sand	0-6	Dark grayish-brown to grayish-brown loose fine sand; contains a small amount of organic matter.
	6-12	Yellowish-brown to brownish-yellow loose fine sand
	12-48+	Strong brown to reddish-yellow or yellowish-red loose fine sand.

Source: U.S.D.A., 1958

in better surface drainage for this region. In addition, the well drained deep sands are less common to this area of the Central Highlands than they are in the Flatwoods.

Hydrology

Most of the aspects of the surface water hydrology of the Hillsborough River Basin, have been discussed with some detail previously in this paper. For this reason, further discussion of the hydrologic character of the study area will include the general characteristics of the ground-water and artesian system. Also, additional analysis of the monthly water balance (Table 13) will be considered.

Ground Water and the Artesian System

Because of the nature of the soils and underlying formations, much of the precipitation that falls on the Hillsborough River Basin goes directly to ground water recharge. The aquifer system underlying the study area consists of three individual aquifers of differing characteristics and depths (Briley, Wild and Associates, 1970). These are in descending order; the water table aquifer, the shallow artesian aquifer and the principal Floridan Aquifer.

The water table aquifer consists of undifferentiated sands, clays and marls of Pleistocene and Pliocene age and is found to depths of 150 feet. Although the clay and marl materials do not yield significant amounts of water, the sands have been known to discharge up to 200 gpm. (Briley et al., 1970). The level of the water table is approximately

ten feet from the surface and follows the topography of the area in a subdued manner. In the Flatwoods, the fairly high water table associated with typically low relief and elevations, results in generally poor soil drainage.

The shallow artesian aquifer is predominantly composed of the Hawthorne formation and is found in some places from the surface to depths of 250 feet. This Miocene formation consists of sands, clays and some porous limestones which yield up to 200 gpm. The significant clay impurities associated with the Hawthorne act as a subsurface aquiclude in many areas of the river basin.

The principal Floridan Aquifer in the study area is made up of numerous differentiated layers of limestone from Miocene to Eocene age. The younger strata of this system are the Tampa and Suwannee limestones which were described previously. Together, they range in depth from 80 to 400 feet. These rock layers yield water up to the rate of 1000 gpm and supply most of the commercial and domestic wells of the area.

Beneath the Oligocene Suwannee limestone lies the Eocene formations of the Ocala group. This group is composed of the Crystal River formation, the Williston formation and Inglis limestone which are found at varying depths from 90 to 300 feet. The rocks of the Ocala group may be described as yellow-gray and brown soft, almost pure limestones. The Crystal River and Williston formations are rarely used as a source of water because of their low

transmissibility. The Inglis limestone, however, in association with the Avon Park and Lake City limestones supply a major source of ground water for the region.

The Eocene Avon Park and Lake City limestones are found at depths of from 200 to 500 feet. They are soft, chalky and cream to brown in color, containing zones of coquina and crystalline dolomite limestone. Together with the Inglis limestone of the Ocala group, these layers generally yield over 500 gpm and have been known to exceed yields of over 5000 gpm in some wells. The deeper limestones of the Floridan Aquifer are not presently used as a source of water in the Hillsborough River Basin. However, the layers of the Eocene Olásmar limestone at depths in excess of 500 feet do provide a potential source of fresh water for the region (Briley et al., 1970).

Recharge to the surface and shallow aquifers of the basin usually occurs after precipitation. Replenishment of the deeper artesian system, however, is more complex. Recharge at greater depths is hampered by the overlying confining beds of the Hawthorne and, in some instances, the Crystal River and Williston formations. Some percolation of water through these beds does occur, but major recharge to these layers is from surface water filtering down through sinkholes and other conduits formed from solution. Reference will be made to this relationship when considering methods of decreasing regional water loss from the hydrologic system.

The Water Balance

Explanation of Thornthwaite's monthly water balance system (Table 13) was begun during the regional classification of climate according to his 1948 method. The theory of the water balance was first introduced by Thornthwaite in 1944. It has been used in this paper as a systematic method of describing the climatic and physical relationships occurring within the study area. Although refinement of methods for calculating certain components of the system is necessary (eg. potential evapotranspiration), this system provides a satisfactory framework for comparison. The figures listed in Table 13 represent theoretical averages and are not meant to portray the exact relationship for each water year. Rather, they have been constructed to demonstrate the possible relationships of the components of the water budget within the study area.

The amount of water available for runoff in any given month is proportional to the water surplus for that month. In watersheds larger than 100 square miles, fifty percent of available moisture surplus runs off (Thornthwaite, 1948). This percentage may be decreased in a smaller basin area. The remaining half of the moisture surplus is detained in the basin until the next month when it is combined with that month's surplus to equal the total available water for runoff. Again, fifty percent of that figure is entered as runoff for the respective month. Using this method

runoff figures were calculated for the study area beginning in July; the first month of water surplus after soil moisture demand was satisfied.

The runoff figures listed in the water balance table represent the total runoff for the study area. Included in these figures are the monthly totals of surface runoff (SRO) and base flow (BF), the two components of runoff. Much of the water surplus in the Hillsborough River Basin goes directly to ground water storage (GWS) and enters the streams as base flow. Base flow is the amount of water contributed to streamflow from the ground water table. Therefore, this component of runoff is directly proportional to the amount of ground water held in ground water storage. The amount of water held in this fashion for any given month, however, is partially determined by the amount of water lost to base flow in the previous month.

Again, it is assumed that in large watersheds, fifty percent of the total ground water storage is released to streamflow and the remaining fifty percent available is held over into the next month. Therefore, ground water storage for any month is equal to the carry-over from the previous month (equal to the base flow from the previous month) plus the present recharge due to soil moisture surplus. The figures for ground water storage were calculated according to the formula:

$$GWS = 0.5 BF_p + S$$

where BF_p is equal to base flow for the previous month and S is the current moisture surplus. Base flow for any given month is a function of the amount of water held in storage. Therefore:

$$BF = 0.5 \text{ GWS}$$

Because these components are dependent upon each other, an arbitrary starting point with an assumed value for ground water storage must be selected for their computation. The month of July was chosen as the point of origin because it was the month after the longest period without ground water recharge. Therefore, during this month, ground water storage was assumed to be equal to the moisture surplus of 2.93 inches. Calculation according to the above formulas was carried out for several annual cycles; each additional cycle was believed to more closely approximate the real value.

The surface runoff figures in the table were determined by subtracting the base flow amounts from the total runoff (RO) for each month.

$$SRO = RO - BF$$

Therefore, in each month, total runoff is equal to combined base flow and surface water runoff. Also, inspection of the annual regional runoff and surplus figures demonstrates that all water in excess of regional demand is accounted for and the system is in balance.

CHAPTER III

HISTORICAL DEVELOPMENT AND LAND USE

Land use changes found in conjunction with expanded urban development have been shown in Chapter I to have a significant impact on the hydrologic characteristics of a watershed. The water balance data for the Hillsborough River Basin listed in Chapter II represents the average monthly distribution of available moisture among the components of the Hydrologic Cycle. Reexamination of the procedures used to compute these figures will show that the balance is based on the local characteristics of temperature, precipitation, vegetation, soil, and geology. Because Thornthwaite's theory of the water balance was used to describe the natural relationships of the physical setting, alterations to runoff figures due to urbanization were not considered. Although agricultural changes of vegetation were used to partially determine soil moisture capacity, the water balance table does not reflect the modifications of the urban situation.

When describing the actual relationships of streamflow and runoff to other components of the Hydrologic Cycle on a local scale, adjustments for differing types of land use are necessary. Miller's Assunpink Creek study

mentioned in Chapter I, demonstrates the hydrologic response of a partially urbanized drainage basin to storm runoff. The initial rapid development of peak discharge was explained as the streamflow response to urban runoff. A common formula to determine peak discharge from a given storm is

$$Q = cIA$$

where Q is peak discharge in cfs, c is the runoff coefficient, I is the intensity of the storm in inches per hour and A is the area of the basin in acres (Bruce and Clark, 1969). The runoff coefficient represents the portion of precipitation that will run off and is basically determined by land use in association with the other factors described in Chapter I. The importance of this factor is evident from the above formula. Several arbitrary runoff coefficients developed by the Tampa Bay Regional Planning Council (1973) for this area of West Central Florida are listed in Table 20.

Because changing land use patterns have such a direct influence on streamflow and the Hydrologic Cycle, it is necessary first to describe the historical development patterns within the study area and then determine their net effect on streamflow for the study period in the Hillsborough River Basin. The major urbanized areas of the region are found within the limits of Hillsborough County. Approximately one third of the study area is located in

Table 20: Runoff Coefficients for West Central Florida

Land Use Types	Runoff Coefficient
Residential	0.5
Industrial and Commercial	0.9
Airports	0.5
Recreational	0.35
Strip Mines	0.75
	0.8
Agriculture	0.3
Undeveloped Areas	0.25

Source: Tampa Bay Regional Planning Council, 1973

the northern half of this political unit (Figure 12). Two areas of increased urban development within the basin, but located in Pasco County, are Zephyrhills and an extension of development around the lakes north of Tampa. Because the change in urban land use patterns has been so small in the upper reaches of the basin, the discussion of historical development and land use will be limited to the northern half of Hillsborough County and the sub-regions of Blackwater and Alligator Creeks.

Settlement and Development to 1940

Late in 1823, the American Government decided that for safe settlement of the Florida Territory, the Seminoles had to be moved to the west. Because of their warlike

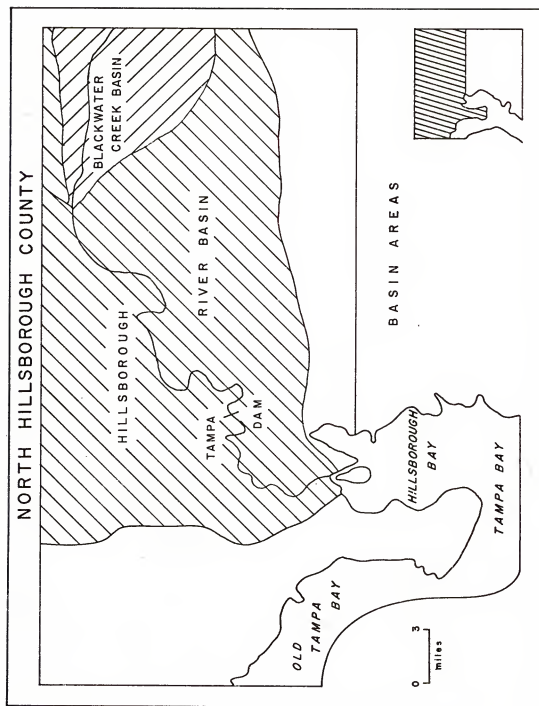


Figure 12

attitude toward white settlement on their land as demonstrated in the Alabama Territory years before, the Army felt that these Indians should be relocated in Oklahoma to enable the opening of Florida. To effectively carry out this government policy, Colonel George Mercer Brooke was commissioned in 1823 to set up an army garrison on Tampa Bay. By 1824, Fort Brooke was established near the mouth of the Hillsborough River. This was the first permanent settlement and development in the Hillsborough River Basin.

The location of Fort Brooke was influenced by the river, the topography, and the operations of the Hackley Plantation. As Colonel Brooke approached the head of Tampa Bay, he found a sizable tract of land on a high and dry portion of the Pamlico Marine Terrace that had been cleared from the thick surrounding forest. This site which was part of the Hackley Plantation (Jahoda, 1973) was also located near the mouth of the Hillsborough River and provided a suitable location for the proposed garrison. Although this intrusion of the military was strongly protested by the Hackley family, Fort Brooke was maintained and became a major center for development on Florida's West Coast.

Not long after its founding, the military importance of Fort Brooke became evident. It served as the major link between the forts and settlements of interior Florida with the outside world. Many of the Indians in the territory had refused to be relocated and leave their land to

white settlers. The Seminoles, under the leadership of Chief Osceola and his successor, Chief Billy Bowlegs, were determined to fight and seek refuge in the swamplands much like their predecessors, the Timucuan and Calusas. The Seminole Indian Wars (1835-1842) discouraged settlement and development of the Florida interior and the Tampa Bay region.

Tampa's next major period of development did not occur until the 1880's because of its relative isolation on the west coast of Florida. By 1880, Tampa was established as a small port, shipping agricultural produce from the interior to the rest of the country. However, in 1884, Henry B. Plant connected Tampa to the interior and other cities to the northeast with the southward expansion of the South Florida Railroad. This ended the region's relative isolation on Florida's sparsely settled west coast.

Along with the railroad, Plant established tourism on the "Suncoast". His Tampa Bay Hotel, which now houses part of the University of Tampa, became known as one of the most luxurious resorts in Florida (Jahoda, 1973). Because of Plant's initiative and influence, along with several other developmental factors, the 1880's and 90's represent a boom period in the growth of the Tampa area.

Tampa's first major industry, cigar making, was established in 1885 by Martinez Ybor and Company. Primary location of these facilities existed in the section of Tampa now known as Ybor City. For many years, cigar manufacturing dominated the area's industrial base.

Because of the nature of what was a hand craft operation, the need for skilled labor encouraged a sizable Cuban Immigration to the region. The strong latin influence established by this cultural group is still noticeable in the city's present population.

In 1888, the South Florida Railroad extended its lines to Port Tampa and dredging operations deepened the port to provide easier access to the Gulf of Mexico. By 1890, Tampa was linked to Plant City, a small agricultural community to the east, and Ocala by the facilities of the Florida Railway and Navigation Company. Port Tampa became a major embarkation point for United States troops during the Cuban Campaign of the Spanish American War (1898). In 1899, large deposits of phosphate were discovered east of the city in Hillsborough and Polk Counties. Phosphate quickly became the port's major export. Today, Tampa is the largest phosphate shipping port in the country.

Tampa grew steadily after the turn of the century through the 1920's. The city spread north and west across the Hillsborough River and south along the bay. Major expansion was influenced by topography and soils as well as the desire for waterfront locations. This customer preference is still an important factor for determining the developmental pattern of the area. The Great Depression of the 1930's marked a temporary end to urban growth in the Tampa area, but the established trends were to continue after economic recovery.

Developmental Patterns 1940 - 1970

By 1940, the influence of topography, soils and drainage was evident on Tampa's urban growth pattern. Figure 13 illustrates the extent of development (urban, agricultural, and industrial) in Northern Hillsborough County in 1940. Most of the City of Tampa and surrounding urban areas developed on high well drained sands. The influence of soil drainage, however, did not determine the total pattern of development. Areas along interbay peninsula grew because of the desire for residence along the waterfront. However, growth east of Tampa to Plant City occurred primarily in the Flatwoods and Polk Uplands. Agricultural development in this area was encouraged by the presence of fertile soil. The hydrologic impact of agricultural development in the poorly drained regions of the study area will be discussed in the next chapter.

Notable areas of urban development may be seen at Tampa and Plant City. Most of the rural development in 1940 existed north and east of Tampa. In contrast, little or no development had taken place in the northeastern section of the county which is composed of very low lying, typically wet flatwoods and swamp area.

Figure 14 shows the extent of developed areas in Northern Hillsborough County in 1948. The figure shows that major urban growth occurred north and east of Tampa as well as around Plant City, but the Northeast sector was virtually untouched. The influence of World War II may be

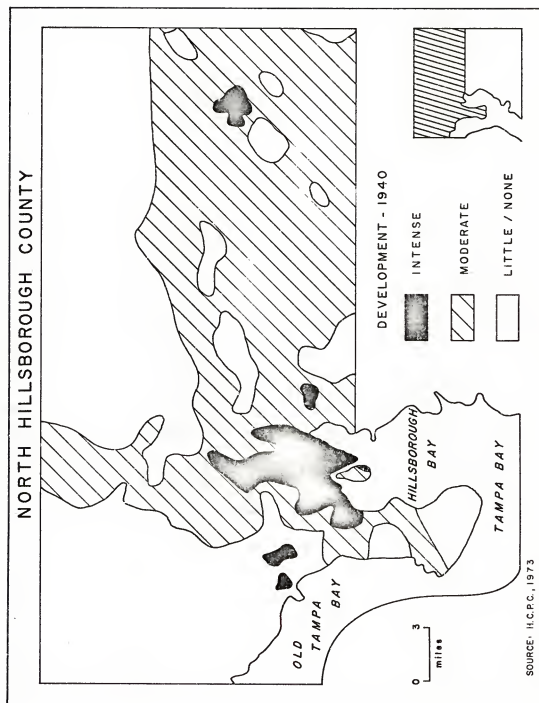


Figure 13

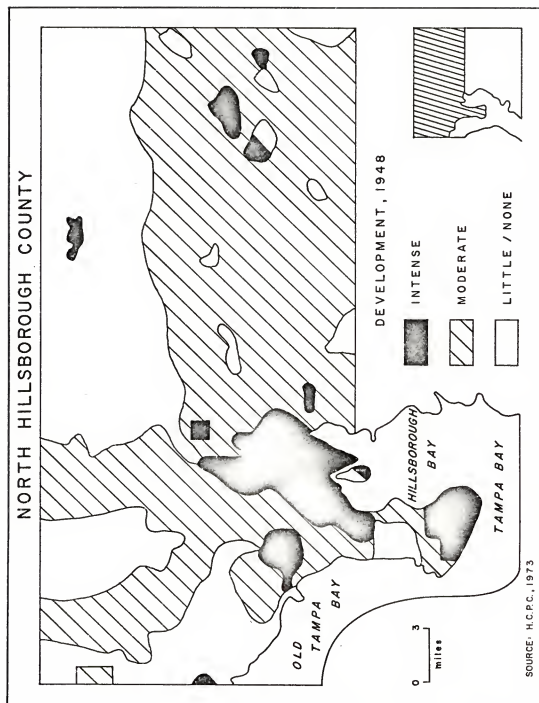


Figure 14

seen by the development of three major airports in the region (Figure 14). MacDill Air Force Base was established on the southern end of the interbay peninsula and has since accounted for much of that area's development. Drew Field, now known as Tampa International Airport, was established west of the city. Henderson Field which was located northeast of the city, has since been given over to the University of South Florida and an industrial park. Between 1940 and 1948, agricultural development, centered around citrus production, extended north and northwest of the city in the lakes region. The only notable change in the flatwoods of the northeastern section of the county resulted from the development of the Hillsborough River State Park.

Figure 15 illustrates the pattern of developed areas as of 1970. From 1948 to 1970 major urban expansion continued to the north and east of Tampa as well as to west and along the interbay peninsula. Increased residential development in the lake areas north and northwest of the city (Lutz and Lake Keystone areas respectively) illustrate the current national trend of suburban development within the rural-urban fringe. The effect of this development and increased population in the western portions of the Tampa Bay Area on the hydrologic characteristics of the lakes region will be discussed in Chapter V. Further inspection of Figure 15 reveals the circumstance of little or no development continuing in the northeast. To better

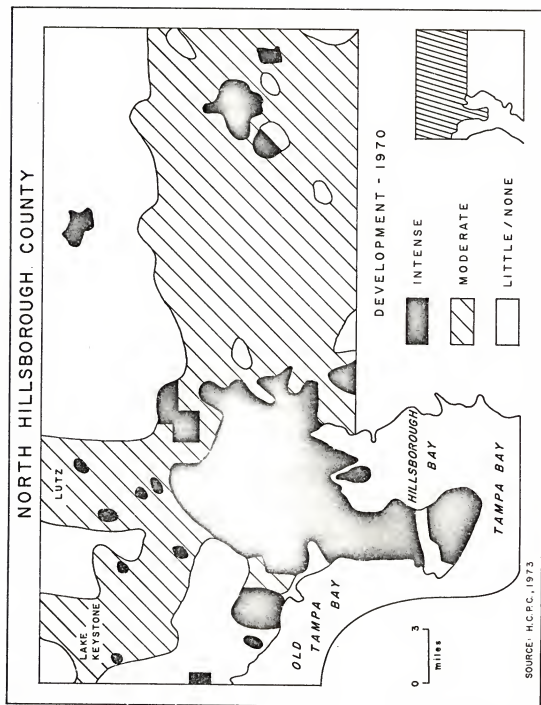


Figure 15

understand the extent of urban, suburban, and residential developmental trends in northern Hillsborough County, a more detailed inspection of the changing population patterns is necessary.

Population Patterns

The general trends of population growth in the Tampa Bay Area and the Hillsborough River Basin have been discussed in Chapter I. Within the thirty year period of record (1940-1970), the population of Hillsborough County has increased from 180,148 to 490,265, a net increase of 172 percent (Table 1). The facilities required to accommodate this growth have changed the physical characteristics of the region.

Figure 16 illustrates the locations of all new subdivisions in Northern Hillsborough County from 1960 to 1970. The greatest concentrations of these new developments are found north and east of the city of Tampa. Although the location map of new subdivisions indicates the areas of greatest developmental activity, it does not show the extent of land use change. Because there is no uniform size governing the extent of an individual subdivision, one large development may in fact alter more surface area than several smaller ones. Furthermore, lot size may exhibit a wide range of values. For this reason, it seems necessary to identify areas of population concentration.

Much of the population increase from 1940 to 1970 in Hillsborough County occurred outside of the central

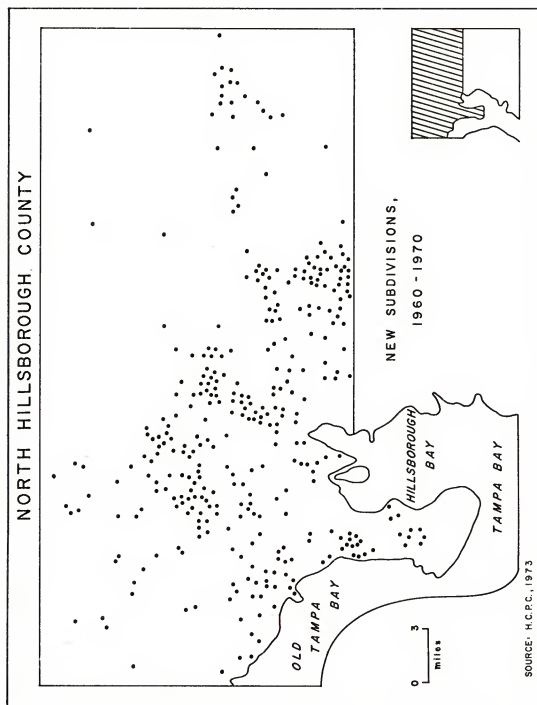


Figure 16

city and was concentrated in the north. Figures 17 and 18 illustrate the pattern of growth in the northern half of the region for the periods 1950 to 1960 and 1960 to 1970 respectively. Numerical increases within an area already under urban development (that is with streets, residential and commercial areas already established) do not result in significant changes in hydrologic relationships in most cases. For this reason, growth within the corporate boundaries of Tampa and Plant City has been deleted in these figures.

Inspection of the two population growth maps points out that there have been five general areas where population increases have been most concentrated. These nodes, located by number in Figure 18, are: 1) The Town and Country Area, 2) Carrollwood, 3) The University Area, 4) Temple Terrace, and 5) Brandon. Three of these centers are located within the limits of the Hillsborough River Basin (Carrollwood, University Area, Temple Terrace) while the others are found on the periphery of the study area. In addition to these growth nodes, other areas of significant population increase from 1950 to 1970 are found in the Lutz and Lake Keystone areas, north and northwest of Tampa respectively, and along the corridor east of Tampa to Plant City.

The data represented in these figures show the relative locations of population growth areas. However, they do not show the extent of land use change created by urban and suburban development. Also, the developmental maps of

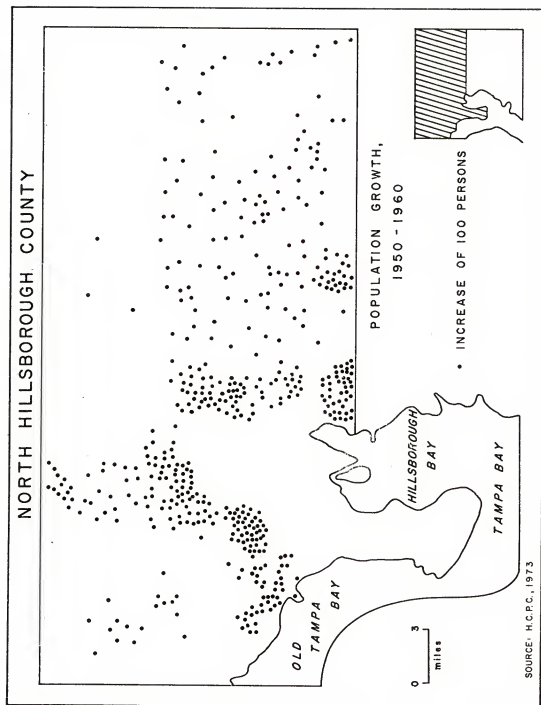


Figure 17

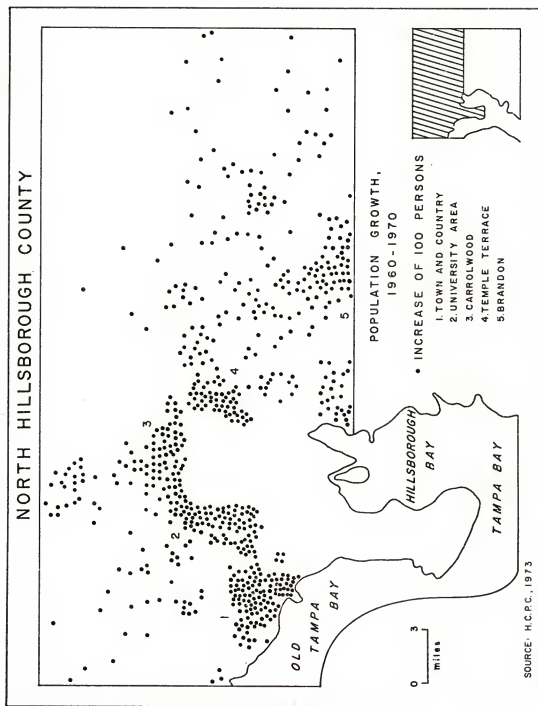


Figure 18

1940, 1948, and 1970 do not spatially differentiate between types of development. Reference to Figure 19 showing 1970 land use, however, will aid in the identification of specific developmental categories.

Land Use

Correlating the areas of population growth with the urbanized areas found on the 1970 land use map of Northern Hillsborough County (Figure 19) will better illustrate the spatial distribution of urban development within the study area. Also, a comparison of the land use patterns shown in this figure with the various developmental maps of 1940, 1948, and 1970 will help differentiate between historical urban and non-urban development. The extent of urbanized area on the land use map includes: 1) single and multi-family residential areas, 2) mobile home residential area, 3) commercial areas, and 4) public and semi-public lands including parks, airports, and universities, etc.

The distribution of urban land within that portion of the Hillsborough River Basin in northern Hillsborough County may be seen by an inspection of Figures 12 and 19. By means of comparison, it is evident that most urban development has taken place below the Hillsborough River Dam (Dam location found in Figure 12). Urbanization above the dam has taken place, for the most part, in association with the urban sprawl of Tampa and is less concentrated than urban development below the dam. Other areas of considerable

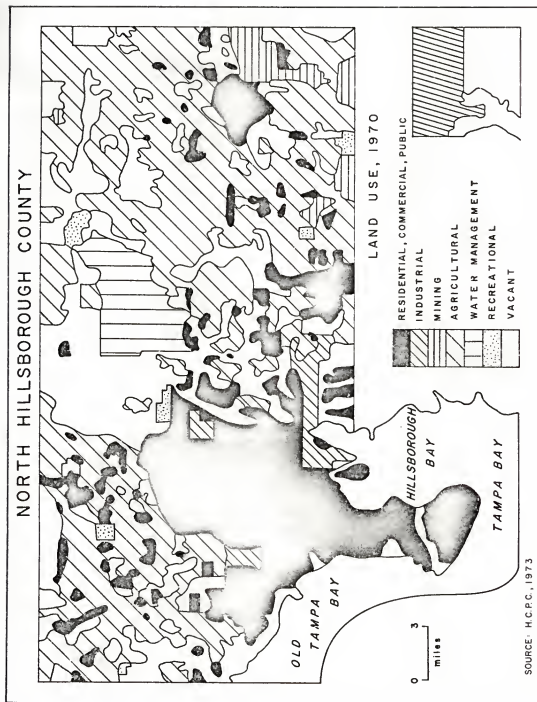


Figure 19

urban development are found in the lakes region to the north and along the major eastern transportation routes going to and including Plant City. Although most of this growth is found within the Polk Uplands, some expansion of urban area has taken place in the Flatwoods.

The danger in using the historical growth patterns of Northern Hillsborough County to illustrate urban development in the study area becomes evident upon inspecting the 1970 land use data for the Hillsborough River Basin given in Table 21. According to these figures only 7.59 percent of the study area is under urbanized land use as defined in Figure 19. However, it is clear from visual inspection, that much more than this percentage of the study area within the limits of Northern Hillsborough County is urbanized. Data given and visual checking both indicate that the vast majority of urban development in the Hillsborough River Basin exists within the northern half of this county. The land use data also points out that almost one half of the study area is undeveloped or vacant and about one third is under agricultural use. The land use map, however, differs in showing a greater portion of agricultural land than vacant land. Much of the study area outside of Hillsborough County is vacant or undeveloped.

The Hillsborough River Basin cannot be considered a highly urbanized area throughout. However, the previous discussion supported by the figures and data found in

Category	Below Dam		Above Dam		Entire Basin	
	Sq.Mi.	%	Sq.Mi.	%	Sq.Mi.	%
Residential	18.74	65.3	12.94	2.21	31.68	5.15
Industrial + Commercial	6.43	22.4	6.35	1.11	12.78	2.1
Airports	0.17	0.6	1.93	0.34	2.1	0.34
Recreational	0.0	0.0	1.79	0.3	1.79	0.29
Strip Mines	0.0	0.0	1.40	0.24	1.40	0.23
Agricultural	0.13	0.5	237.11	40.5	237.24	38.6
Streams and Lakes	0.27	0.9	30.85	5.2	31.12	5.07
Undeveloped	2.96	10.3	293.67	50.1	296.63	48.22
Total	28.7	100%	586.04	100%	614.74	100%

Source: Tampa Bay Regional Planning Council, 1973

Note: The data for this table was compiled by first delineating the river basin on topographic maps using drainage patterns and contour separation. After establishing the region in this fashion, corresponding aerial photographs were used to determine the extent of each land use category.

Table 21 point out that considerable urban development has taken place in the lower reaches of the basin. In addition, as population growth continues in this area, further urban and suburban development is expected to follow current trends. The probable hydrologic impact of this new development will be discussed in the conclusion of this study.

Sub-Region Land Use

In order to determine what the effect of urbanization has been on streamflow in the Hillsborough River Basin, the sub-regions of Blackwater Creek and Alligator Creek near Safety Harbor will be analyzed. The explanation and justification of the use of these basins were discussed in Chapter I. Before any conclusions on altered streamflow due to increased urbanization can be drawn, changes in land use for the period of record must be determined.

Blackwater Creek Basin

The relative location of the Blackwater Creek sub-basin within the Hillsborough River watershed can be seen in Figure 12. From comparison of Figures 13 through 18, it is evident that little or no urban development has taken place in this region. Subsequently, the basin has remained relatively unchanged with over 83 percent of the total area still under native vegetation. The major alterations which have taken place are found in association with agriculture. In addition, some minor commercial and

residential development has occurred along the major transportation routes crossing the basin. The land use types are listed in Table 22. Although this data was compiled in 1963, little or no change occurred to 1970. Because the majority of the Blackwater Creek Basin is still in the natural state, this sub-region will act as a comparative control to determine the basic relationship between precipitation and streamflow in the Hillsborough River Basin. Once this relationship has been established, its comparison with the relationship between precipitation and streamflow in an urbanized basin will suggest the hydrologic impact of urban development in the study area.

Alligator Creek Basin

Alligator Creek which was chosen to illustrate the urban situation for this study, is located in the Tampa Bay area (Figure 1). Within the period of record, significant land use change to urban development has taken place in this sub-region. Inspection of aerial photographs and topographic maps shows very little urban development in this area by 1954. However, by 1970 considerable development consisting mostly of residential expansion had taken place.

Figure 20 illustrates the urban land use change in the Alligator Creek Basin from 1954 and 1970. The watershed boundary was determined by inspection of drainage divides in the Safety Harbor, Clearwater, Oldsmar, and Dunedin topographic quadrangles. Urban land use changes

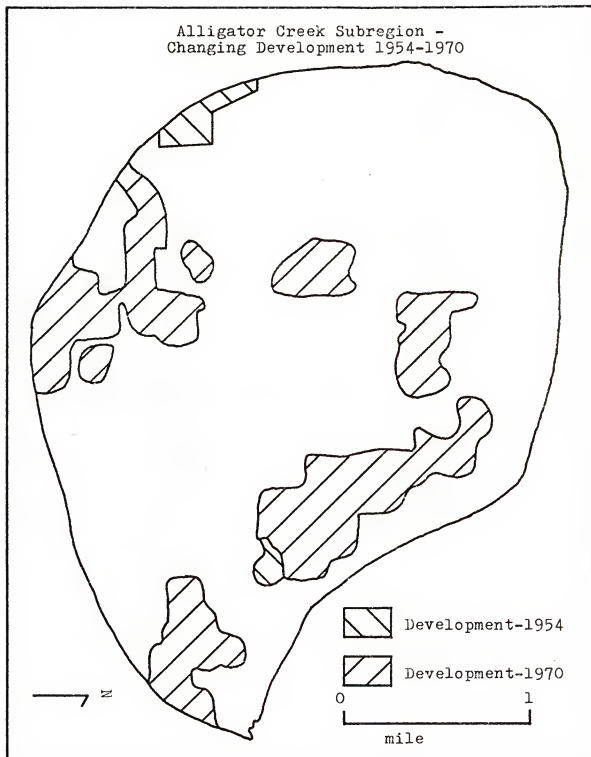


Figure 20

Table 22: Blackwater Creek, Land Use - 1963

Land Use Type	Acres	Sq. Miles	% of Total
Agriculture			
Citrus & Truck	6,282	9.82	5.5
Pasture	12,230	19.10	10.6
Total. Ag.	18,512	28.92	16.1
Native Range & Woodland	96,688	151.08	83.9
Basin Total	115,200	180	100

Source: Forney, Note 1

were developed primarily from 1969 United States Geological Survey revision to the Safety Harbor Quadrangle along with inspection of aerial photos and several field checks. The results shown on this map coincide with the figures provided by the Tampa Bay Regional Planning Council (1973).

The data listed in Table 23 shows the areal extent of differing types of land use in this sub-region as of 1970. By combining the first four categories to represent urban or urban related land use, it can be seen that over one third of the watershed was urbanized by this date. Further inspection of these figures will show that less than ten percent of the area was under agriculture and over half was undeveloped by 1970. Most areas of agricultural land use, consisting predominantly of citrus production, existed prior to the period of record. Therefore, the majority of recent land use change in the Alligator Creek Basin resulted from urban expansion.

Table 23: Alligator Creek, Land Use - 1970

Land Use Type	Acres	Sq.Mi.	% of Total
Residential	1395.2	2.18	22.47
Industrial + Commercial	512.0	0.80	8.25
Airports	185.6	0.29	2.99
Recreational	25.6	0.04	0.42
Agriculture (Citrus)	582.4	0.91	9.38
Streams & Lakes	204.8	0.32	3.30
Undeveloped	3302.4	5.16	53.20
Total	5208	9.70	100

Source: Tampa Bay Regional Planning Council, 1973

The general effect of this urban expansion may be determined by an examination of the runoff coefficient relationship. By combining the runoff coefficients listed in Table 23, a weighted urban runoff coefficient may be determined for the region. In the same manner that the Thiessen mean precipitation was calculated in Chapter II, this new runoff coefficient may be determined according to the formula:

$$C_w = \frac{c_1 a_1 + c_2 a_2 + c_3 a_3}{A}$$

where C_w is the weighted runoff coefficient, c , and a , are the runoff coefficients and area under each respective type of land use, and A is the total of areas 1, 2, 3.

Application of this formula to the Alligator Creek Basin results in an urban runoff coefficient of 0.57978 for the region. Considering that over one third of the basin has become urbanized during the study period and that the percentage of storm precipitation that will run off has more than doubled, it is evident that the streamflow of Alligator Creek has been affected. The extent to which streamflow has been altered by these changes will be discussed in Chapter V.

CHAPTER IV

FLOW EXTREMES AND THE F.R.B. PROJECT

One of the most important hydrologic characteristics of a river basin with respect to urbanization is the frequency of flooding. Floods are a natural fluvial geomorphic process and their repeated occurrence has created some of the best agricultural soils in the world. However, continued urban development in floodplain areas has led to a great deal of research on the issue of extensive areal flood control and hazard-zone occupance.

W. M. Kollmorgen (1953) debates whether the protection of tentative urban locations justifies the loss of vast agriculturally productive areas to the process he terms "Floodplain Cannibalism". With increasing population and the need for expanded agricultural productivity, a choice such as this must be considered carefully. Ian Burton and R. W. Kates (1964) consider another sociologically important issue. In a comparative analysis of development in coastal and riverine flood prone areas, they found that the floodplain resident is considerably less aware of his hazard-zone occupance than the coastal dweller. With this low level of social awareness, floodplain development has continued in many areas with little consideration

for even frequent hydrologic events such as the five year flood. The economic implications of these two studies alone demonstrates the need for continued research on flooding.

Wisler and Brater (1967) define a flood as that stage at which a stream channel becomes filled and above which it overflows its banks. However, the level of these banks varies throughout the river's course. Therefore, no one stage can be determined as that point where a river becomes completely flooded. Rather, a detailed study of numerous points along the course of a river is necessary to best establish flood stage. In addition to this definition, for the purpose of this study, a flood will be considered as any usually dry land subsequently covered by water.

For the most part, river floods are caused by significant increases in surface runoff. Although precipitation provides the basic source of this increased runoff, it is difficult to estimate the amount of flooding created by one storm of specific magnitude and duration. Because base flow contributes such a large part to streamflow in the Hillsborough River Basin, the pre-storm level of this component will greatly influence the point at which bank-full stage will be attained at any given location. From the discussion of the components of the Hydrologic Cycle in Chapter I and the runoff coefficient in Chapter III, it is evident that land use changes can have a significant impact on surface runoff. There are several factors found

in combination with precipitation that have a direct effect on the magnitude and frequency of flooding in the Hillsborough River.

Flooding in the study area is not limited to river bank overflow. Because of the characteristics of soil and topography in the Hillsborough River Basin, major hydrologic events can cause extensive soil flooding. A discussion of the relationships causing floods of this type along with a detailed analysis of the magnitudes and frequency of river floods will follow.

Soil Flooding

Soil flooding, for the purposes of this study, is not directly related to riverine floods. Rather, the term refers to the occurrence of standing water on normally dry ground, created by intense precipitation, exceeding the infiltration rate of the soil. The occurrence of soil floods in the low lying regions of the Hillsborough River Basin is not uncommon. Traditionally, flood studies have focused on coastal and floodplain inundation. However, as agricultural and urban expansion took place in the study area, marginal lands which experienced fairly frequent soil flooding were developed. Development in these area quickly increased social awareness of this problem and consideration of soil flood frequency subsequently influenced the pattern of urban development in the region.

Although the frequency of this phenomena helped shape the basin's developmental pattern, as observed in Chapter

111, it neither determined the entire pattern nor completely inhibited development in all sections of the Flatwoods. Some urban and extensive agricultural developments have taken place in this physiographic region. Historical practices used to decrease the soil flood hazard and their influence on the hydrologic characteristics of the region will be discussed later in this chapter. This section will focus on the factors which increase soil flood probability and frequency in the Hillsborough River Basin.

Soil flooding generally occurs as a result of one of two situations: 1) normal surface storage exceeded by short period, high intensity rainfall and 2) a ground water rise above ground surface directly related to high seasonal precipitation. The first situation represents the most common type found in many areas of the basin. Figure 21 illustrates possible damage which can occur from even brief periods of soil flooding in this case due to the lack of necessary precautions by contractors and developers. Soil floods of this type, which result from the precipitation rate exceeding the infiltration capabilities of the soil, generally have a duration period from several minutes to possibly several hours. This time factor is dependent upon the porosity and permeability of the soil along with the current soil moisture characteristics of the area. If soil moisture capacity is small, flood duration will depend on the percolation characteristics of the soil. This rate determines the time necessary for excess water to move to the ground water table. If the level of the ground water



Figure 21: Soil Flooding. Water seepage from soil flooding shown here caused minor interior damage to this house in the Lime-sink region of the study area. Flood duration in this instance was approximately one half hour, however, residents have reported considerable damage to woodwork and carpeting sustained from flooding of longer duration.

table is sufficiently high prior to the storm, then longer flood duration will result from soil flooding.

As mentioned in Chapters I and II, when there is sufficient seasonal precipitation, a portion of available moisture will go to the ground water recharge. In low lying areas where the ground water level is high due to extensive recharge or high potentiometric head, soil flooding of the second type is more common. Duration of standing water in this situation is usually much longer than in the previously mentioned type of soil flood. Ground water flooding may last from several days to several

months depending on regional characteristics. Because the moisture conditions are important in the soil forming process, they have a significant influence on subsequent soil classification. Research has shown, that particular soil types have a definite relationship to the ground water table and soil flood frequency (U.S.D.A., 1969). Table 24 lists several characteristics for each of the major soils found in the study area and describes their overall ground water flood hazard.

Comparison of Table 24 with the distribution of soil types discussed in Chapter II shows that the major soils of the Lime-sink region flood less than once in fifty years. For all practical purposes, there is no ground water flood hazard in this region. Further inspection of this table, however, shows that the soils of the Flatwoods and Polk Uplands are much more susceptible to this type of flooding.

The frequency of flood hazard for the soils of these physiographic regions is estimated to be once in five to twenty years (U.S.D.A., 1969). A review of the physical characteristics of each of these physiographic regions found in Chapter II will lead to further refinement of this prediction. Table 24 lists the overall flood hazard for each soil type. Consideration of relative relief and elevation in each region tends to indicate that recurrence of ground water floods is closer to once in five years in the Flatwoods and once in twenty years in the Polk Uplands. Because a five year flood is not an

Table 24: Ground Water Flood Hazard of Specific Soil Types in the Hillsborough River Basin

Soil Type	Depth (In.)	Permeability	Relation to Seasonally High Water Table		Overall Flood Hazard	
			Depth (In. from surface)	Duration (mo./yr.)	Frequency	Duration
Leon fine sand	0-20 20-26 26-42+	6.3 0.63-3.0 6.3	0 to 15	1 to 2	1 in 5 to 20 yrs.	1 wk. to 1 mo.
Immokalee fine sand	0-32 32-38 38-42+	6.3 0.63-2.0 6.3	0 to 15	1 to 2	1 in 5 to 20 yrs.	1 wk. to 1 mo.
Ruskin fine sand	0-24 24-36+	6.3 2.0-6.3	0 to 15	1 to 2	1 in 5 to 20 yrs.	1 wk. to 1 mo.
Sunniland fine sand	0-20 20-30	6.3 2.0-6.3	0 to 15	1 to 2	1 in 5 to 20 yrs.	1 wk. to 1 mo.
Adamsville fine sand	0-42+	6.3	15 to 30	less than 1	1 in 5 to 20 yrs.	1 wk. to 1 mo.
Blanton fine sand	0-42+	6.3	15 to 30	less than 1	Less than 1 in 50 yrs.	
Lakeland fine sand	0-60 60+	6.3 0.2-0.63	More than 120	12	Less than 1 in 50 yrs.	
Eustis fine sand	0-48+	6.3	More than 120	12	Less than 1 in 50 yrs.	

Source: U.S.D.A., 1969

infrequent hydrologic event, soil flooding must be considered in any future developmental plan for the Flatwoods region.

Channel Flooding and Prediction

Floods of Record

The major floods occurring in the Hillsborough River Basin have resulted from increased volumes of direct runoff created by large storm or significant storm sequences. Streamflow records for the Hillsborough River date back to 1933. Since this date numerous floods have occurred in the study area, the most severe of which were in September, 1933, March, 1960 and September, 1960.

The flood of 1933 was associated with intense precipitation from a tropical hurricane which passed over central Florida in September of that year. Rainfall volumes of ten to fourteen inches were recorded in a thirty-six hour period at many stations in the area (U.S.A.C.E., 1962). Peak discharge of 16,500 cfs caused failure of the Tampa Electric Dam on the Hillsborough River. The subsequent release of reservoir storage resulted in considerable area of Tampa. Discharge of 16,500 cfs recorded during this flood still remains as the maximum discharge recorded in the river basin.

In 1960, there were two separate periods of flooding in the Hillsborough River Basin. The first occurred in March of that year resulting from a series of storms caused

by a stationary front located over central Florida. Prior to these storms, moisture storage in the basin was near full capacity due to relatively high precipitation in the preceding months. Therefore, when numerous high intensity storms released up to twenty-seven inches of rainfall near Tampa between March 15 and 18, high volumes of surface runoff and streamflow occurred (U.S.A.C.E., 1962). Peak discharge of 14,600 cfs resulting from this flood accounts for the second highest discharge of record in the study area. Pertinent data from this maximum flood of 1960 is listed in Table 25.

The third ranking discharge figure in the Hillsborough Basin is 13,500 cfs caused by Hurricane Donna in September, 1960. In addition to high precipitation from this storm, the flood magnitude in this instance was augmented further by antecedent wet conditions in the basin. The summer of 1960 was extremely wet with many stations in peninsular Florida recording from twenty-five to forty-five inches of precipitation (U.S.A.C.E., 1962). When high precipitation from this hurricane occurred, severe flooding resulted.

Frequency Estimates

In order for adequate planning and floodplain zoning to effectively decrease flood hazard in the study area, the recurrence interval of these major hydrologic events must be determined. It is economically impractical to establish a flood control program designed for a three hundred year

Table 25: Hillsborough River Basin - March 1960 Flood Data

Flooded Area (square miles)	263
Average Duration (days)	10
Frequency (years)	55*
Maximum State Near Tampa (ft.)	22.9
Maximum Discharge (cfs)	14,600**

Source: U.S.A.C.E., 1962

* According to the U.S. Army Corps of Engineers report in 1962, a flood of this magnitude or greater had a frequency of once in thirty years. However, according to the Gumble frequency plot used in this section, the recurrence interval more closely approaches once in 55 years. Because the latter estimate is based on a longer period of record, it is considered to be more accurate.

** Maximum discharge for the flood of March, 1960 in the Hillsborough River Basin is listed as 15,600 cfs in House Document No. 585. However, after checking several references including Turner (1974) and actual U.S.G.S. Streamflow records for the study area, maximum discharge for this flood was 14,600 cfs.

event. However, in most cases, projects with a design flood of one hundred years are practical because they can be implemented at a lower cost and still minimize the overall effects of extremely rare floods.

There are numerous methods available to estimate storm runoff in a river basin. Generally these methods may be grouped into three major categories (Wisler and Brater, 1967). These are: 1) Empirical formulas, 2) Unit hydrograph analysis, and 3) Statistical probability methods. Analysis of the limitations of each of these general methods, and consideration of the available data and desired accuracy

for the study, established the latter of these methods as most suitable for use in the Hillsborough River Basin.

Of these methods of classification, empirical formulas seem the least suited for flood prediction as required in this study. Most of these formulas are used to estimate the amount of runoff from a storm of a given duration and intensity and not estimating the recurrence of a flood of a given magnitude. Unit hydrograph analysis is thought to be the most dependable method for determining flood frequencies (Wisler and Brater, 1967). However, use of this method is limited to watersheds small enough so that precipitation is fairly uniform throughout. From the discussion of variable precipitation on the Hillsborough River Basin in Chapter II, it is evident that the characteristics of the areal distribution of rainfall in the study area casts doubt on the usefulness of this technique. Although the use of statistical methods also has various limitations, the primary restrictions are less prohibitive than those of the other methods.

The accuracy of statistical probability is increased with the length of the period of record. For example, a significant error may be expected when estimating the magnitude of a one hundred year flood from a ten-year period of record. Because records for the Hillsborough River are available for over thirty years, estimates determined by this process are considered fairly accurate for flood magnitude with recurrence intervals of up to

sixty years. Although a slight error is expected for higher return periods, these estimates are considered to be acceptable for purposes of this study.

There have been numerous methods developed by statisticians which can be used for frequency analysis of hydrologic data. Because of their wide usage for flood frequency analysis by many hydrologists, the Pearson Type III and Type I Extremal Distributions (Chow, 1964) were initially considered for this study. The Pearson Distribution, however, exhibited several restrictions for use. Included in these were severe limits for estimates ranging beyond fifty year recurrence intervals and a resultant skewed J or bell-shaped curve. Linearization of the Type I Extremal or Gumble Distribution along with the lack of restrictions for estimates of extreme values were important criteria for selection of this method. By establishing the relationship between stream discharge and frequency for the common lower values, simple extension of the linear distribution results in credible estimates for higher more infrequent values.

The Gumble Distribution adopted for this study was derived by plotting discharge against return period on Gumble-Powell probability paper (Chow, 1964). Stream discharge in an annual series was determined by selecting maximum flow at the Tampa Dam for each year of record. The recurrence interval or return period for discharge of a given magnitude is that period of time within which that flow will

be equaled or exceeded. This figure was calculated according to the formula:

$$RI = \frac{N + 1}{m}$$

where RI is the recurrence interval, N is the period of record, and m is the respective rank according to greatest magnitude for the period (Chow, 1964). Table 26 lists the values for each component used in this frequency distribution.

Figure 22 illustrates the Gumble frequency curve for the Hillsborough River at the Tampa Dam. Analysis has shown that the mean annual flood should be equaled or exceeded at least once every 2.33 years (Leopold, Wolman and Miller, 1964). According to the curve in this figure, discharge with a return period of 2.33 years is equal to 4,600 cfs. The mean annual flood for the period of record is equal to 4,705 cfs. Because of the length of record and the relatively small discrepancy in these figures, this curve is considered to give an accurate estimate for flows with return periods of up to sixty years. A slight error may be expected for greater magnitudes.

Flood Profiles

Once flood frequency for a river basin has been established, it is next necessary to determine the extent of flooding which will occur from flows of specific magnitudes. This may be done by first determining relative river stage for various discharges and then delineating

Table 26: Recurrence Intervals for Annual Maximum Flows
at the Tampa Dam

Rank	Discharge (cfs)	Year	Recurrence Interval (yrs.)
1	16,500	1933	34.00
2	14,600	1960	17.00
3	9,600	1945	11.33
4	8,900	1950	8.50
5	7,580	1947	6.80
6	7,390	1959	5.66
7	6,830	1953	4.85
8	6,340	1965	4.25
9	5,420	1949	3.78
10	4,940	1964	3.40
11	4,900	1969	3.09
12	4,520	1967	2.83
13	4,500	1941	2.62
14	4,130	1948	2.43
15	4,100	1970	2.27
16	3,830	1962	2.13
17	3,810	1957	2.00
18	3,370	1968	1.88
19	3,290	1943	1.79
20	3,180	1958	1.70
21	3,090	1963	1.62
22	3,040	1966	1.55
23	2,980	1939	1.48
24	2,890	1954	1.42
25	2,610	1946	1.36
26	2,230	1942	1.31
27	1,980	1955	1.26
28	1,900	1952	1.21

Table 26 - Continued

Rank	Discharge (cfs)	Year	Recurrence Interval (yrs.)
29	1,770	1944	1.17
30	1,500	1951	1.13
31	1,300	1940	1.10
32	1,260	1961	1.06
33	810	1956	1.03

Note: Data for water years 1934-1938 not available.

flooded area according to respective contours along the floodplain. River stage for a given discharge may be determined by the Step Method described by Chow (1959).

Using a similar method developed by the U.S. Geological Survey, Turner (1974) determined profiles for floods with various recurrence intervals for the lower Hillsborough River Basin. Water levels for each flood were calculated for over fifty channel cross sections between Tampa Dam and Fletcher Avenue. Table 27 lists the respective stage at six of these cross sections for four various flood discharges. Flood profiles (Figure 23) were determined by plotting stage against the distance above the Tampa Dam.

One of the major problems involved in estimating flood profiles with respect to recurrence intervals was related to the operation of Tampa Dam and water supply reservoir. Since its completion in October, 1945,

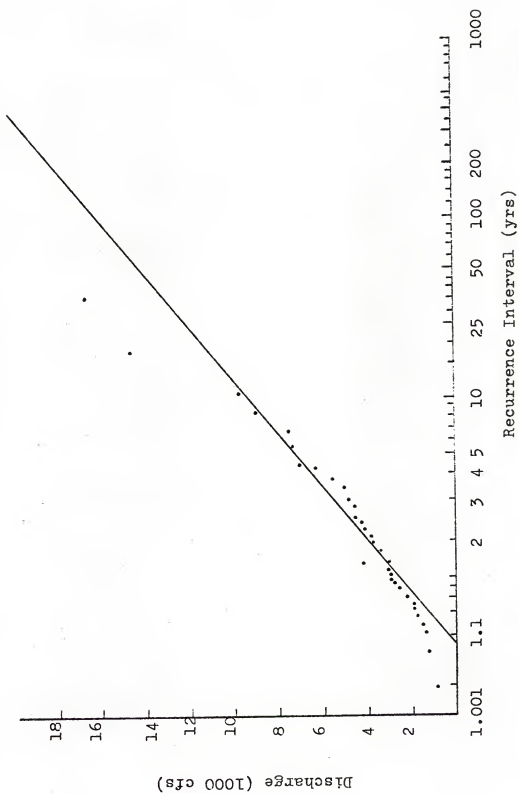


Figure 22: Gumbel Frequency Distribution - Hillsborough River
at Tampa Dam

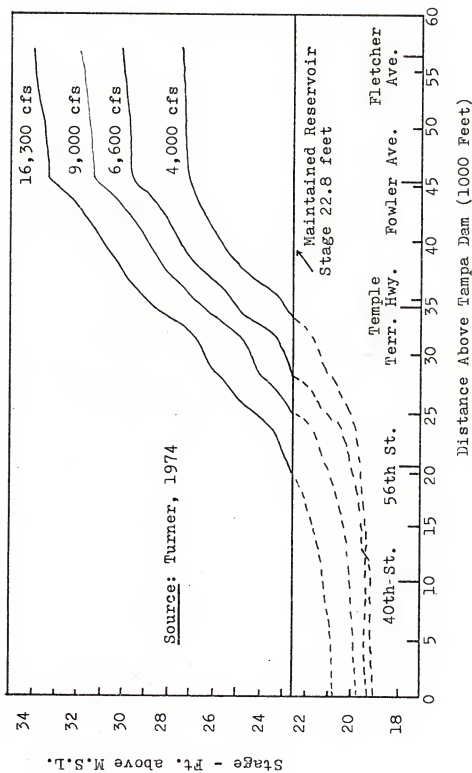


Figure 23: Flood Profiles of the Lower Hillsborough River

Table 27: Flood Profile Data for the Hillsborough River Basin - Tampa Dam to Fletcher Avenue

Cross Section	Distance Above Dam (ft.)	Computed Water Levels for Various Flood Discharges (cfs)			
		4,000	6,000	9,000	13,000
Near Tampa Dam	20	19.30	19.10	19.80	20.70
40th Street	10,090	19.37	19.31	20.12	21.23
56th Street	19,540	19.65	20.02	21.10	22.65
Temple Terrace	33,870	21.36	22.96	24.42	26.44
Fowler Ave.	45,250	27.27	29.65	31.25	33.25
Fletcher Ave.	56,380	27.57	30.14	31.91	34.08

Source: Turner, 1974

Note: Figures for locations near Tampa Dam and 40th Street show some discrepancy for stages below 22.8 feet. This results from the effect of Tampa Dam on the system as mentioned in the text.



Figure 24: Tampa Reservoir. This reservoir view of the Tampa Dam illustrates the radial crest gates installed early in 1962 after flash boards were destroyed in the March 1960 flood. Maximum retention capacity of this facility is 22.8 ft.



Figure 25: Tampa Dam. Comparison of this front view of the Tampa Dam with the water level seen in Figure 24 illustrates the decreased river stage created by this facility.



Figure 26: Lower Hillsborough River. The natural channel of the Hillsborough River a short distance downstream of the dam is only partially filled. The small islands seen here are associated with bedrock outcrops exposed by decreased river stage.

streamflow has been restricted downstream of this facility. Figures 24, 25 and 26 illustrate this present relationship. When possible, the dam maintains reservoir stage at 22.8 ft. Therefore, the recurrence intervals and flood profiles below this stage can only be empirically estimated (Turner, 1974).

The Four River Basins Project

The association between the natural characteristics of variable seasonal precipitation and drainage in west central Florida has frequently led to periods of either an over abundance or shortage of available moisture. The major floods of the period of record were discussed previously in this chapter. Also during this time, however, there were two drought periods occurring in 1940, and 1954-56. Of these, the 1954-56 drought was the most severe, with precipitation averaging only forty-one inches per year in the area. Throughout the study period, an alternating sequence of high and low flow has been recorded in the basin. In the last forty years, increased agricultural and urban development have accentuated the normal expected variation in water supply.

Figures 27 through 30 illustrate the occurrence of an additional drought in the early summer of 1975. According to Mr. Paul Hahn of the City Water Department, storage in the reservoir was estimated to be at its lowest level since construction of the facility. Increased sedimentation resulting from altered channel



Figure 27: Stage Recorder. This stage recorder illustrates the level of the Tampa reservoir in mid-May, 1975. At that time, low stage was measured at about 17 feet and bars created by increased sedimentation were exposed in the background.



Figure 28: Tampa Reservoir - Low Level. Comparison of the May water level with the normal water level markings seen in this photo, indicate the relative areal shrinkage of the Tampa reservoir during the drought of 1975.



Figure 29: Intake Structure. Water marks on this intake structure illustrate the drop in stage due to decreased streamflow. Water level at this time was less than two feet above the facility's lowest intake pipe shown here.

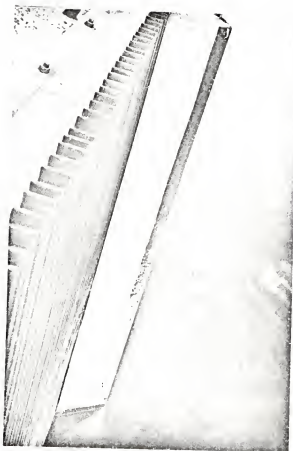


Figure 30: New Intake Structure.
Because of the severe low stage experienced in the early summer of 1975, new reservoir intake structures are being built at lower levels.

conditions has decreased the storage capacity of the reservoir. Therefore, although the stage of the reservoir is no lower than that experienced during the drought of 1954-56, actual water storage is at a lower level.

Historically, periodic flooding in the flatwoods generated little concern because major development was concentrated on higher ground. However, early agricultural developers discovered that some of the better soils of the area were located in the flatwoods, but these were subject to fairly frequent flooding. To decrease the occurrence of soil flooding during extremely wet periods, farmers constructed drainage ditches to move excess water to lower areas and nearby streams. This practice had a tendency to overtax the lower drainage systems and thus increased the magnitude and frequency of channel flooding. In addition, it also increased the actual water loss of the hydrologic system. In the natural state, water retention of this type acted as a source of local ground water recharge, which in turn added to base flow during low flow periods. Thus, as drier periods occurred, water shortages became more acute.

As population increased in the basin, more economical, marginal agricultural and urban areas were developed (Figures 13 to 20). Increased water loss due to this expansion intensified peak flows and decreased low flow in many of the smaller tributaries to the Hillsborough. In addition, urban development increased along lake fronts

and on floodplains. This type of urban growth supports the conclusions reached by Burton and Kates in their 1964 hazard-zone study. A more detailed analysis of the impact of this urban expansion on discharge in the Hillsborough River will be considered in Chapter V.

By the early 1960's, the need for a comprehensive water program for west central Florida was evident. Aside from the problem of modified river regimes and variable water supply, as urbanization expanded in flood prone areas, damages due to normal flooding increased significantly. The floods of March and September of 1960 created an estimated \$11.4 million damage (U.S.A.C.E., 1962). Flood control, however, would only solve half of the area's water problem. By this time, the need for a more stable supply of water had already been established.

General Plan of Development

In 1966, construction began on the Four River Basins Project based on the 1962 report of the Army Corps of Engineers to the House of Representatives (House Document No. 585). Legislation provided for a detailed flood control and water conservation program covering over 6,100 square miles in west central Florida. The areas affected by the project included the river basins of the Hillsborough, Peace, Oklawaha, and Withlacoochee Rivers along with several coastal basins (Anclote and Pithlachascotee Rivers and Lake Tarpon Basin). The locations of these areas can be seen in Figure 31.

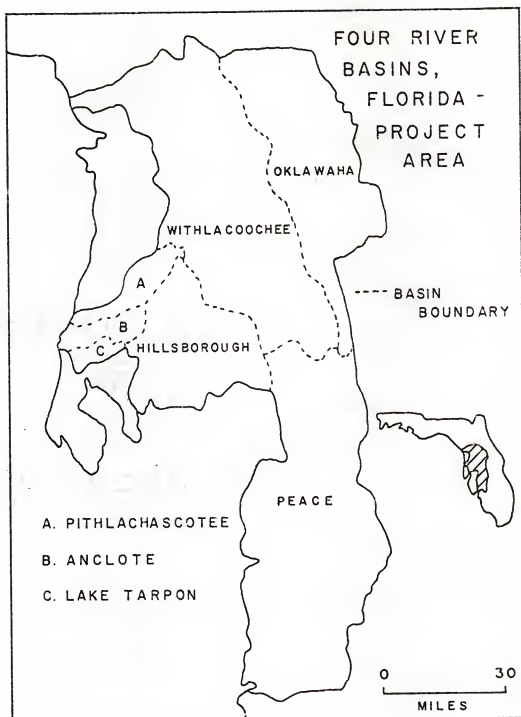


Figure 31

A flood control project designed simply to remove excess water from the region would, in fact, intensify the problem of water shortage during dry periods. Therefore, the Four River Basins (F.R.B.) Project proposed storing flood waters in strategically located reservoirs throughout the region. These storage sites would include natural lakes, valley reservoirs, and levee-restrained side hill reservoirs. Excess water retained by these methods would not only provide a source of fresh water for the region, but also contribute an additional source to ground water recharge and offset water loss of the system to the sea. In addition, flood retention reservoirs would also serve as recreational areas as well as providing facilities for fish and wildlife management and conservation.

Each retention area would be connected to major streams by existing channels which would be enlarged to accommodate increased flow. Where possible natural channels would be maintained, using floodplains as an integral part of the spillway. This practice would require restricted development in these areas. In some cases, however, artificial channels would be necessary to carry excess flood water. Such alterations to the natural basin will be mentioned in the next section of this chapter. For purposes of this study, a discussion of the comprehensive plan for development will be limited to the Hillsborough River Basin and the areas directly adjacent to and affecting the study area.

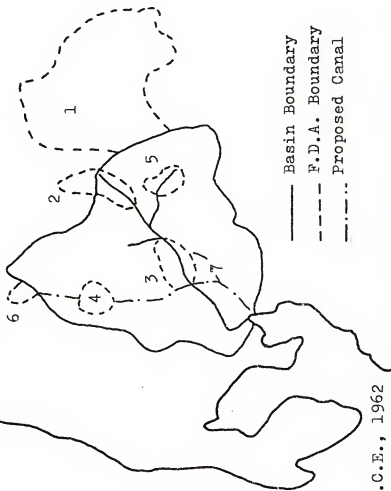
The 1962 Proposed Plan For The Hillsborough River Basin

According to the Four River Basins Plan, a series of four storage reservoirs have been proposed in the Hillsborough River Basin. As seen in Figure 32, these flood detention areas are: 1) the Upper Hillsborough F.D.A., 2) the Lower Hillsborough F.D.A., 3) Blackwater Creek F.D.A., and 4) Big Cypress F.D.A. In addition to these reservoirs and their associated outlets, the Tampa Bypass and Thonotosassa Outlet Canals and the Green Swamp and Squirrel Prairie F.D.A.'s have also been proposed to divert flood with a recurrence interval of two hundred years. The operational design for these facilities, however, has not yet been firmly established. Final determination of critical flow magnitudes which will require gate and spillway operation will be made in mid-1976 (Note 2).

The Green Swamp F.D.A. The Green Swamp Flood Detention Area will cover 61,700 acres near the middle of the Green Swamp and have an average retention capacity of 460,000 acre feet ($567.405 \times 10^6 \text{ M}^3$). The preliminary area-volume curves are shown in Figure 33. During periods of high water, natural surface runoff and ground water recharge from this region enters all four of the major river basins in the project area. The plan, however, provides for retention and subsequent distribution of flood waters through the Hillsborough and Withlacoochee Watersheds. Of the four major rivers in the study, the U.S. Army Corps

1962 F.R.B. Plan - Hillsborough River Basin

- Proposed Facilities
1. Green Swamp F.D.A.
 2. Upper Hillsborough F.D.A.
 3. Lower Hillsborough F.D.A.
 4. Big Cypress F.D.A.
 5. Blackwater Creek F.D.A.
 6. Squirrel Prairie F.D.A.
 7. Tampa Bypass and Thonotosassa Canals



U.S.A.C.E., 1962

Figure 32

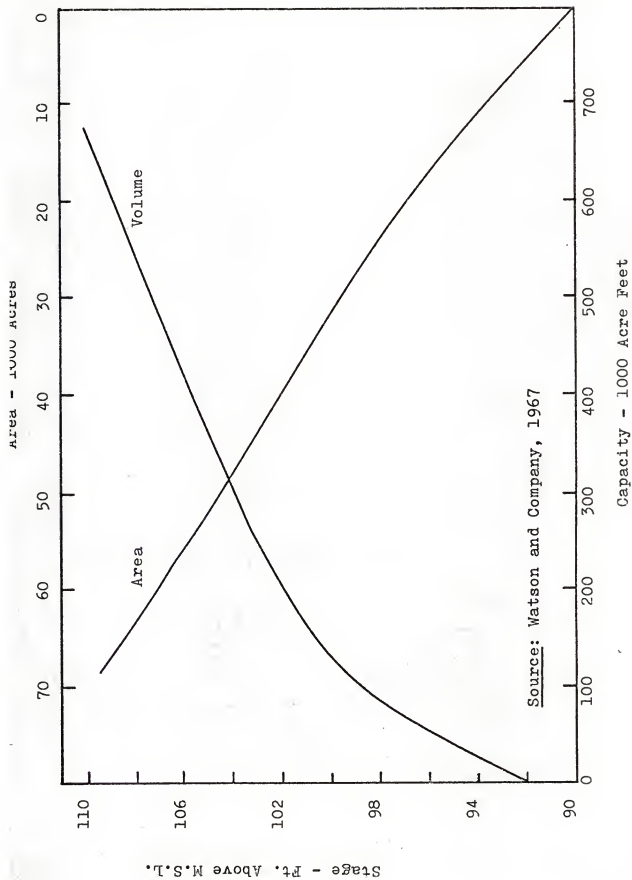


Figure 33: Green Swamp Reservoir - Area-Volume Curves

of Engineers determined that the Hillsborough would provide the best outlet for excess water from the Green Swamp. This determination was based on relative distance to the sea and the extent of channel modification required to accommodate increased streamflow. However, implementation of this phase of the project will require complete facilities at the Lower Hillsborough Reservoir and the Tampa Bypass Canal to provide flood protection for the city of Tampa.

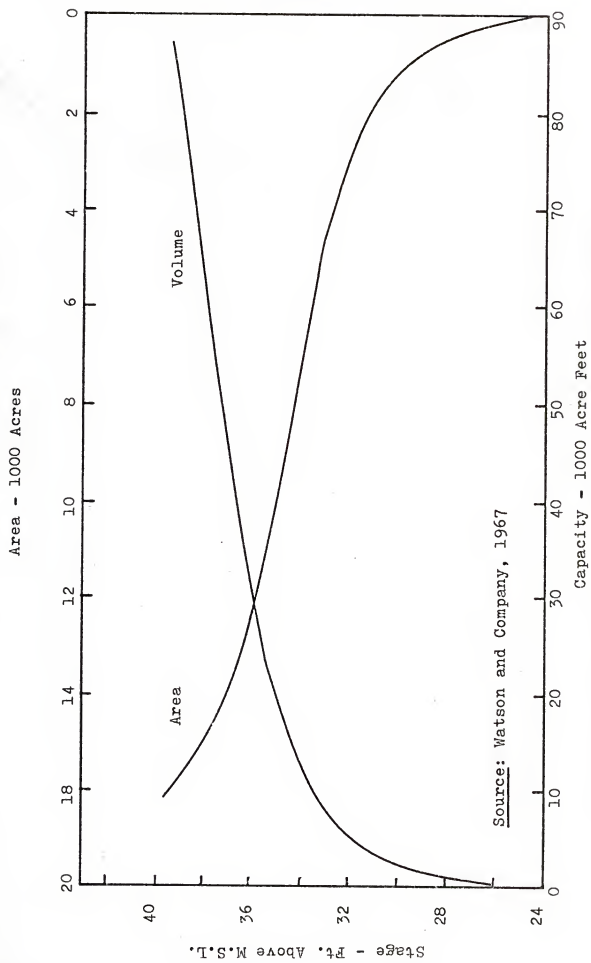
The proposed Green Swamp structure will consist of a hillside-type reservoir created by a twenty-three mile retaining levee on the north and west sides. It will also contain an outlet to the Withlacoochee River which in turn will direct excess discharge to the Upper Hillsborough Reservoir. Construction of the Green Swamp Flood Detention Area is scheduled to begin in February of 1979 (Note 3).

The Upper Hillsborough Flood Detention Area. The Upper Hillsborough Flood Detention Area is to be located across the divide between the Hillsborough and Withlacoochee Rivers. This facility will cover over 11,500 acres and have a capacity of 48,000 acre feet ($59.207 \times 10^6 \text{ M}^3$). Control structures located at each end of this reservoir will allow diversion of flow to either or both rivers as required. As previously mentioned, primary diversion will be to the Lower Hillsborough Reservoir through the unimproved channel. However, during flood periods when this reservoir nears

full capacity, excess flow will be directed through the Withlacoochee Basin. Land acquisition has begun for this facility, but to date a construction schedule has not been established (Note 3).

The Lower Hillsborough Flood Detention Area. The Lower Hillsborough Flood Detention Area is to be located southwest of the Hillsborough River State Park, several miles upstream from the present site of the Tampa Dam and Water Works. The water management area shown in Figure 19 illustrates the extent of land acquisition for this facility as of 1970. When completed, the reservoir will cover over 17,300 acres and have an average storage capacity of 79,000 acre feet ($97.446 \times 10^6 \text{ M}^3$) (Figure 34). Under normal conditions, water from this reservoir would flow to Hillsborough Bay through the unimproved channel. During flood flows, however, outlets would be opened to divert excess water to the Tampa Bypass and Thonotosassa Canals to insure protection of the urban areas of Tampa and Temple Terrace downstream of the dam. Enlargement of the channel through these urban areas, however, will be required to accommodate increased flow from urban runoff. Construction of the restraining levees required for the Lower Hillsborough Reservoir is scheduled to begin in the spring of 1976 (Note 3).

Big Cypress F.D.A. Initial construction for the Big Cypress Flood Detention Area has been proposed for the spring of 1977 (Note 3). Upon completion, the average



Source: Watson and Company, 1967

Figure 34: Lower Hillsborough Reservoir - Area-Volume Curves

capacity for this reservoir will be approximately 97,000 acre feet ($119.648 \times 10^6 \text{ M}^3$) covering an area of about 12,600 acres in south central Pasco County. The preliminary area-volume curves related to reservoir stage are shown in Figure 35. Discharge from this flood detention area will be directed through the enlarged Cypress Creek channel to the Lower Hillsborough Reservoir.

Blackwater Creek Flood Detention Area. The Blackwater Creek Flood Detention Area would have an average capacity of 50,000 acre feet ($61.674 \times 10^6 \text{ M}^3$) and cover an area in excess of 9,000 acres just north of Plant City. The reservoir would result from impoundment of water by topographic restrictions and an extensive levee along its entire west side. Principal discharge from this facility would be through the unimproved channel and floodplain of Blackwater Creek to the Lower Hillsborough Reservoir. As of September, 1974, neither land acquisition nor proposed construction schedules had been established (Note 3).

Squirrel Prairie Flood Detention Area. Although the Squirrel Prairie Flood Detention Area would be established outside of the Hillsborough River Basin, its function would be to divert excess flow from the Masaryktown area and the Pithlachascotee River Basin to the Big Cypress Reservoir. The operation of this facility would periodically provide an additional source of streamflow to the study area. This flood detention area would have an average

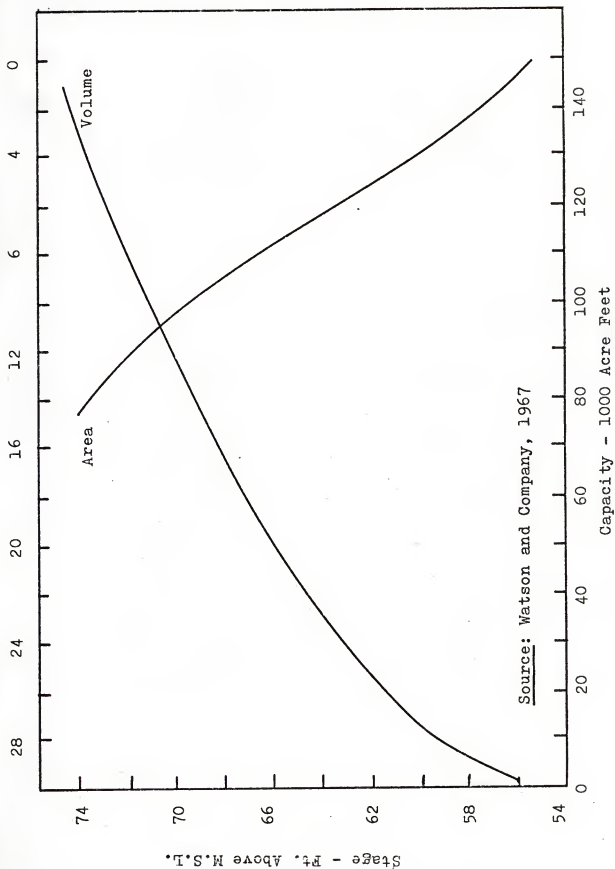


Figure 35: Big Cypress Reservoir - Area-Volume Curves

capacity of 12,000 acre feet ($14.802 \times 10^6 \text{ M}^3$) and cover an area of approximately 2,700 acres in Southern Hernando and Northern Pasco Counties. As of 1974, scheduling and land acquisition had not yet begun (Note 3).

Tampa Bypass and Thonotosassa Outlet Canals. In addition to the control structure of the Lower Hillsborough Reservoir, the Tampa Bypass Canal would provide a second outlet for flood water from this flood detention area. The canal would divert excess flow from the southeastern end of the reservoir around the urban areas of Tampa and Temple Terrace directly into McKay Bay. When completed, this facility will consist of: 1) a new levee restrained canal from the Lower Hillsborough F.D.A. to Cowhouse Slough, 2) the improved Cowhouse Slough channel, 3) a second levee restricted canal from Cowhouse Slough to Six Mile Creek near Buffalo Avenue, and 4) the improved Six Mile Creek channel to McKay Bay.

The Thonotosassa Outlet Canal would provide a third outlet from the Lower Hillsborough Reservoir. This artificial channel would connect the upper reaches of the F.D.A. to the Tampa Bypass Canal and allow flow to be diverted in either direction. During normal flow periods, water would be directed through Lake Thonotosassa and Flint Creek to the reservoir. During flood flows, however, excess water from the eastern portion of the county and the upper portions of the reservoir would be directed to the bypass canal.

Present Status of the F.R.B. Plan

Since the original proposal of the Four River Basin Project in 1962, significant research on the feasibility of each aspect of the plan has been conducted by the Southwest Florida Water Management District and the U.S. Army Corps of Engineers. As a result, several problems have been discovered and suitable revisions proposed. Cost-benefit studies have also shown several portions of the original plan to be economically unsound, thus causing their probable deletion from the project.

One of the major problems affecting the F.R.B. Plan in the Hillsborough River Basin has been created by the combination of relative low relief and high potential evapotranspiration in the region. As previously mentioned, the primary objectives for the plan are to provide adequate flood control and stabilize the region's water supply during low flow periods. Because of the lack of deep topographic depressions capable of retaining large volumes of water, the proposed reservoirs were to cover large areas at fairly shallow depths.

Such reservoir construction results in large surface areas of exposed water, thus increasing regional water loss to evaporation. Because of regionally high potential evapotranspiration, the magnitude of this water loss would adversely alter the water supply potential of several of the proposed flood detention areas. Preliminary study has shown that only three of the reservoirs are capable of

satisfying the dual purpose of the project (Watson and Company, 1967). These are the Green Swamp, Lower Hillsborough and Big Cypress Flood Detention Area.

According to Mr. Robert Moresi of the Southwest Florida Water Management District, construction of the Squirrel Prairie, Blackwater Creek and Upper Hillsborough F.D.A.'s along with the Thonotosassa Outlet Canal is questionable. Because of increased construction costs and rising land values, those portions of the original plan which provide only flood control are economically impractical. The premise set forth by Kollmorgen in 1953 that "Settlement Control Beats Flood Control" has been recognized in the revised plan. Floodplain zoning and regional planning will dominate in decreasing flood hazards in the undeveloped portions of the study area.

In addition to these probable deletions, several other revisions have been made to the 1962 plan. Emphasis on flood control in the Big Cypress Flood Detention Area has been expanded to include provisions for increasing water supply. This facility now known as the Cypress Creek F.D.A. will primarily function as a ground water recharge area for the new Cypress Creek well field. Wells in this area will provide water to Pinellas and Pasco Counties and the City of St. Petersburg. This will decrease the stress on the Cosmi-Lutz well fields in Northwest Hillsborough County presently supplying these areas. The hydrologic impact of ground water depletion in this area will be discussed in Chapter V.

Several additions to the Tampa Bypass Canal have also been proposed to increase its potential in the water supply program for the region. The primary function of the bypass canal is still to divert flood water from the Hillsborough River around Tampa and Temple Terrace to McKay Bay. Figures 36 and 37 show the progress on this project to date. To insure further flood protection for the Tampa urban area in the lower basin, the Harney Cutoff Canal has been proposed to divert excess urban runoff from the river downstream from Temple Terrace to the bypass canal. The revised plan also offers the capability of recycling 50 mgd of tertiary-treated sewage from Tampa's waste water treatment plant at Hookers Point to the Hillsborough River.

Presently, ill-treated sewage is being discharged into Tampa Bay. Completion of the city's proposed tertiary sewage treatment plant which will provide potable water, along with the new provisions of the bypass canal to carry it, will potentially increase the area's water supply during low flow periods. From this increased flow in the canal, 30 mgd could be pumped to the Hillsborough River three miles upstream from the city water works by means of a horizontal well.

It should be remembered that the revised plan only provides the capability for recycling waste water in the future. Presently, social prejudice to this practice hampers current implementation of such a plan. However, after sufficient research and educational efforts on the



Figure 36: Completed Tampa Bypass Canal. The Tampa Bypass Canal has been completed south of Buffalo Avenue to McKay Bay. This photo illustrates the improved Six Mile Creek channel just south of the Buffalo Avenue Bridge.

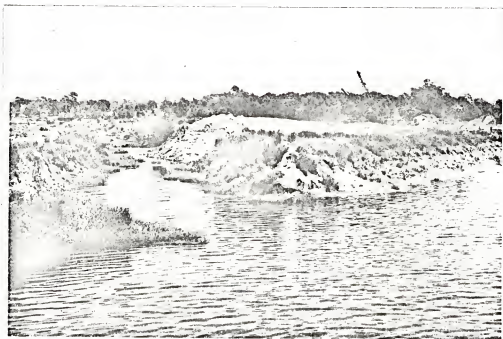


Figure 37: Tampa Bypass Construction. In June, 1975, construction was beginning on the Tampa Bypass Canal north of Buffalo Avenue. This photo illustrates the unimproved portion of the channel during relatively low flow.

suitability of all aspects of recycled tertiary treated water, acceptance of this plan seems probable, particularly as water becomes relatively scarce.

CHAPTER V

IMPACT OF INCREASED URBANIZATION ON THE HYDROLOGIC CHARACTERISTICS OF THE HILLSBOROUGH RIVER BASIN

In Chapter III, it was shown that there has been considerable urban expansion in the Hillsborough River Basin between 1940 and 1970. Reexamination of Table 21 reveals that only 7.59 percent of the total area is under urban land use. However, within the 28.7 square mile area downstream from the Hillsborough River Dam, over 88 percent of the watershed is urbanized. Although this localized area only accounts for a small portion of the total basin, the high degree of urban density found there is believed to have altered the hydrologic component of streamflow within the period of the study.

As discussed in Chapters I and II, the basic components of streamflow in the Hillsborough River Basin are surface runoff and base flow. The amount of precipitation that will enter a stream as direct runoff is determined by the surface characteristics of the basin. The level of the ground water table will determine the amount of water that will enter a stream as indirect runoff or base flow. Therefore, any adjustment in either of these elements caused by increased population and related urban expansion will ultimately affect streamflow.

A review of Chapter I will also show that increased urbanization may either increase, decrease or have no marked effect on streamflow. It is the purpose of this chapter to establish the relationship between urbanization and streamflow in the Hillsborough River Basin from 1940 to 1970. This will be accomplished by first examining alterations to the level of the ground water table (base flow) and surface runoff characteristics created by expanded urban area in the region. Once these effects have been determined, a more detailed look at a rural and urban subarea will be necessary to establish the overall impact of urbanization on streamflow in the major watershed. This will be done by empirical hydrograph and double mass curve examination patterned after studies by Miller (1966) and Seaburn (1969).

Statistical analysis will also be used to establish the relationship between these two variables in each subarea. Analysis of data from the rural basin will determine to what extent the variation in streamflow is explained by variation in precipitation in a natural watershed. Comparison of these results with those established in a similar geologic, but urban watershed will determine to what extent urbanization has altered streamflow. Empirical analysis will reveal whether streamflow has increased, decreased, or remained the same. Statistical analysis will establish the magnitude of any change which has taken place. By combining these methods, a more precise relationship between urbanization and streamflow will be determined.

Base Flow and the Ground Water Table

The contribution of base flow to streamflow in the Hillsborough River is most evident during relatively dry periods which are experienced periodically in the study area. During drought periods, the streamflow of the river is sustained primarily by Crystal Springs in the upper basin and Sulphur Springs below the Tampa Dam. Locations of these areas of ground water outflow may be seen in Figure 38.

Both Crystal and Sulphur Springs act as a source of discharge from the deep lying Floridan Aquifer. As mentioned in Chapter II, the major source of rapid local recharge to this system is from percolation and seepage of ground water from the overlying surface and shallow aquifers. In addition to recharging the Floridan Aquifer and subsequently adding to the flow of Crystal and Sulphur Springs, the surface and shallow aquifers also add, although to a lesser extent, directly to the base flow of the river and its tributaries. Therefore, any change in the level of water in these systems will have a ultimate effect on streamflow in the region.

The Floridan Aquifer

Increased urbanization in West Central Florida has had a two-fold impact on the water level of the Floridan Aquifer in the region. Primarily, surface changes due to expanded urbanization have altered the recharge relationships of the surface and deeper aquifers. Also, related to increased urbanization, there has been a greater demand

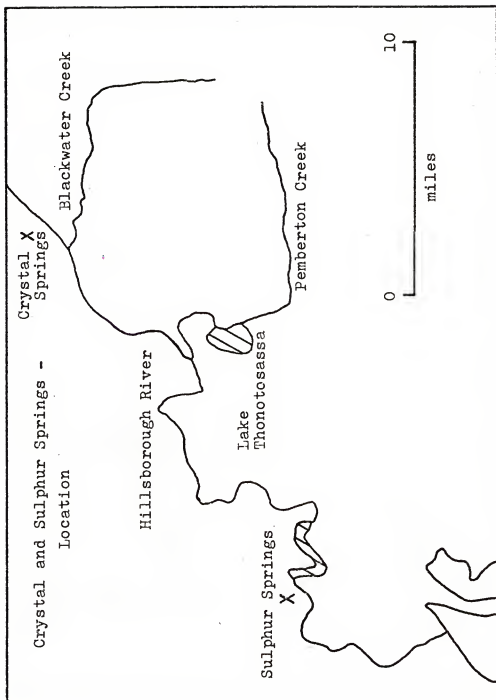


Figure 38

for water consumption to meet human, cultural and industrial needs. Therefore, in addition to decreasing local recharge of the aquifer system, increased ground water use had also helped in lowering the potentiometric surface of the Floridan Aquifer in the study area.

Figure 39 shows the relative change in potentiometric surface of the Floridan Aquifer from 1949 to 1969 in West Central Florida. A more detailed illustration of the actual change in this level may be seen by inspection of the hydrograph in Figure 40. This hydrograph was compiled from long term readings of the water level in a well located in the extreme western portion of the Hillsborough River Basin. Its actual location may be seen in Figure 39.

It is brought out in Figure 40 that the potentiometric surface of the Floridan Aquifer decreased approximately thirteen feet in this portion of the study area in the twenty year period 1949 to 1969. This decrease may be explained by: 1) increased draw down due to increases in the previously mentioned consumptive uses, 2) the extended drought periods of the mid 50's and 3) increased restrictions to local recharge by increased urban land use. Although there were several floods within this twenty year period, their effect on ground water recharge were minimized by the characteristics of the intensity and duration of the precipitation. There was significant ground water recharge during these flood periods, however, much of the potential recharge was lost due to rapid surface runoff. Thus the

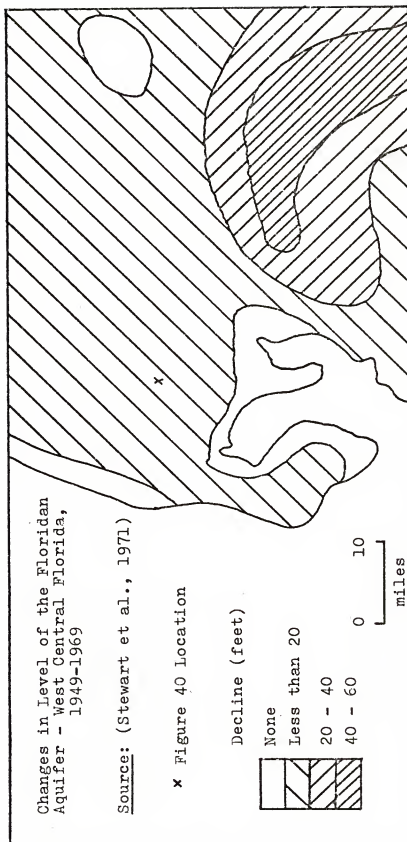


Figure 39

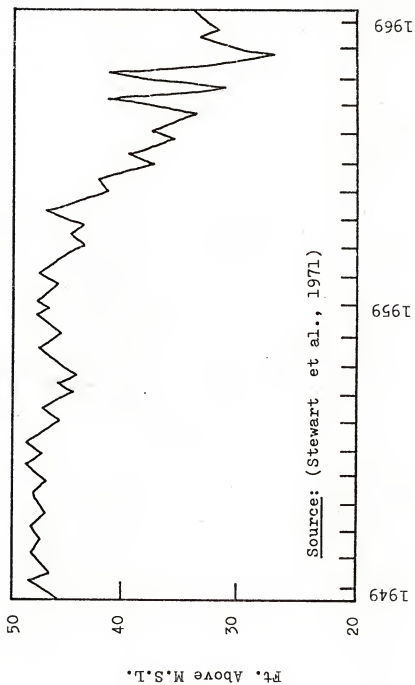


Figure 40: Potentiometric Surface of the Floridan Aquifer - Hillsborough County, Florida, 1949-1969

overall effect of the alternating drought-flood sequence did little to increase the ground water table.

Figure 41 shows the change in potentiometric surface of the Floridan Aquifer from 1964 to 1969 and more clearly illustrates the general areas of increased aquifer draw down during the latter part of the study period. Further inspection of this figure indicates that there are two distinct areas of rapid ground water depletion in the study area. Each of these areas has been created by increased consumption from outside of the study area.

The most extensive region of ground water depletion is located in the southeastern portion of the basin and includes much of the basin of Blackwater Creek. Increased draw down in the major aquifer of this area has occurred in conjunction with extensive phosphate mining and production in Polk County. The other major area of ground water depletion is found in the western portion of the lakes region of the Hillsborough River Basin. Depletion in this area is more closely related to urbanization and expanded consumption by the increased population of Pinellas County. In this case, expanding urbanization, although outside of the Hillsborough River Basin, has affected the hydrologic relationships within the study area. For this reason, a more detailed discussion of ground water depletion in this area will follow.

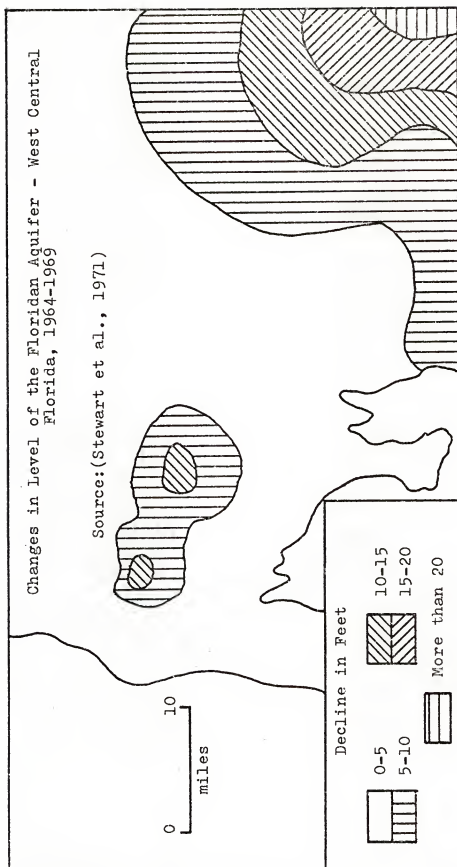


Figure 41

Ground Water Depletion in Northwest Hillsborough County

Unlike Hillsborough County, Pinellas County has no significant fresh water streams capable of providing a viable source of water for its population. Therefore, the people of Pinellas County have had to tap the ground water reserve for a source of fresh water. Several factors, however, have made complete reliance on the local artesian system impossible. These are: 1) the large volume of water necessary to meet the requirements of the area's population, 2) decreased recharge area within the county caused by expanding urbanization, and 3) the effects of salt water intrusion on the depressed water table near the coast.

Most of the public water system of Pinellas County pump water from remote areas of the Floridan Aquifer. Table 28 lists these systems as of 1970 and identifies their general source of ground water. From this table, it can be seen that the City of St. Petersburg and the Pinellas County facilities provide the major source of water to most of the systems in the county. The primary well fields for the City of St. Petersburg are the Cosmi-Odessa and Lutz fields located in Northwest Hillsborough County. The Pinellas County system received most of its water from the Eldridge-Weild well fields located in Northeast Pinellas County. Continued draw down by pumping in these areas combined with pumping from the Port Richie and New Port Richie well fields in Southwest Pasco County

Table 28: Public Water Systems of Pinellas County

Name of System	Source of Supply
1. Pinellas County	Remote - Floridan Aquifer
2. St. Petersburg	Remote - Floridan Aquifer
3. Belleair	Local - Floridan Aquifer (No. 1 used as stand-by)
4. Clearwater	Local - Floridan Aquifer (Supplemented by No. 1)
5. Dunedin	Local - Floridan Aquifer
6. Largo	Number 1 provides
7. Oldsmar	Number 2 provides
8. Safety Harbor	Number 1 provides
9. Pinellas Park	Number 1 provides
10. Gulfport	Number 2 provides
11. Tarpon Springs	Number 1 provides 90% - the balance is taken from the local Floridan Aquifer

Source: Briley, Wild and Associates, 1970

has created the noticeable depressions in the level of the potentiometric surface of the Floridan Aquifer as seen in Figure 41.

Visual evidence of increased ground water depletion can be seen by examining the lake levels of the region. However, a brief examination of lake formation in the area is first necessary to understand the relationship between ground water depletion and fluctuating lake levels. There are three types of lakes in Northwest Hillsborough County and the western portion of the Hillsborough River Basin (Briley, Wild and Associates, 1970). These are: 1) water table lakes, 2) artesian or sink hole lakes, and 3) perched lakes.

Water table lakes are found in depressions which intersect the level of the surface or shallow aquifer. Therefore, changes in the level of the ground water table are reflected in the levels of these lakes. Artesian or sink hole lakes are directly connected to the local artesian system. Changes in the potentiometric surface of the Floridan Aquifer are shown by fluctuations in their levels. Perched lakes are those which are found in depressions that collect water due to the impervious character of their bottoms. These lakes act as simple surface water retention basins and their levels are determined by the local precipitation-evapotranspiration relationships rather than ground water fluctuations. Most of the lakes in the area of the Lutz well field, found in the lakes region of the

Hillsborough River Basin, and the Cosmi-Odesa well fields, found in Northwest Hillsborough County, are lakes of the first classification (Briley et al., 1970).

Although most of the lakes in this region are water table lakes sustained by the shallow aquifer, extensive pumping from the Floridan Aquifer has affected the level of several of these lakes. As mentioned in Chapter II, major recharge to the Floridan Aquifer is from the overlying water holding units. As the hydraulic differential between these units is increased by decreasing the potentiometric surface of the lower artesian system, there is increased percolation from the upper aquifers. Thus there is a general tendency to lower the levels of the local water table lakes (Figure 42).

The effect of intensive pumping from the Floridan Aquifer, however, has not been extensive on all lakes in the region. Rather, the greatest impact has been on lakes in the proximity to the areas of pumping within the Lutz and Cosmi-Odesa well fields. One such lake where the effect of increased draw down is evident is Lake Rogers in the Cosmi-Odesa field in Northwest Hillsborough County.

Figure 43 illustrates the relative areal shrinkage of Lake Rogers from 1949 to 1971. The maps in this figure were derived from aerial photographs taken in those years. Considering that average precipitation was antecedent to each photograph, lake shrinkage is attributed to a decrease in the ground water table.



Figure 42: Lowered Lake Level. This photograph of a water table lake in Northwest Hillsborough County was taken in August, 1972 and illustrates the effect of ground water depletion in the region.

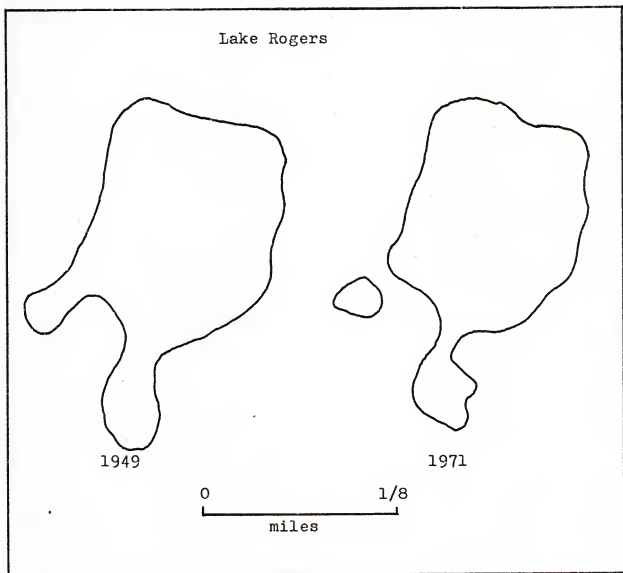


Figure 43

Table 29 lists a partial record of ground water consumption from Hillsborough County for the City of St. Petersburg. The city has extensive facilities in Hillsborough County including a water treatment and pumping station (Figure 44) and numerous well heads scattered throughout its two major well fields (Figure 45). Operation of these facilities at the magnitude shown in Table 29 has caused a relative lowering of the water level in the shallow aquifers of the area, resulting in a decrease in the level of Lake Rogers.

Figure 46 shows that by August, 1972, the southern extension of Lake Rogers had become separated from the main body of water. The numerous well heads which fringe the lake, such as that shown in Figure 47, have intensified the overall effect of ground water depletion in this area. Use of a simple dot grid pattern to measure relative areas in Figure 43 shows that between 1949 and 1971, the areal extent of Lake Rogers had decreased by 37 percent.

Although the decrease in the level of Lake Rogers has been caused by intensive pumping from the Floridan Aquifer, it does not reflect the common reaction of all the lakes in the region to ground water depletion. Rather, it illustrates the possible effects of this depletion on other lakes if draw down continues at a rate which far exceeds the recharge ability of the local aquifer system. The effects of ground water depletion, similar to those

Table 29: Average Ground Water Withdrawal From Well Fields of Northwest Hillsborough County for Various Years

Well Field	Year	Average Annual Rate of Withdrawal
Cosmi-Odessa Field	1931	2.3 mgd
	1961	19.6 mgd
	1966	5.2 mgd*
Lutz Field	1963	5.3 mgd
	1964	12.6 mgd
	1965	13.2 mgd
	1966	17.6 mgd

* The reduction of the withdrawal rate in the Cosmi-Odessa Well Field between 1961 and 1966 reflects the origination of operations in the Lutz Field in 1963.

Source: Briley et al., 1970

which have occurred in Lake Rogers, are found in several other lakes of the region where intensive pumping has taken place in the immediate vicinity of the lake. Two such examples are Starvation Lake, on the western periphery of the Hillsborough River Basin and Round Lake in the Lutz well field.

Ground water depletion has not been the only result of urban activity which has decreased local lake levels. With increased demand for water front property, the dredging of fairly shallow lakes to increase their desirability for surrounding development has become common. Where lakes



Figure 44: St. Petersburg Facilities. The City of St. Petersburg's facilities in Hillsborough County include this water treatment and pumping station located in the Cosmi-Odessa well field near Lake Keystone.

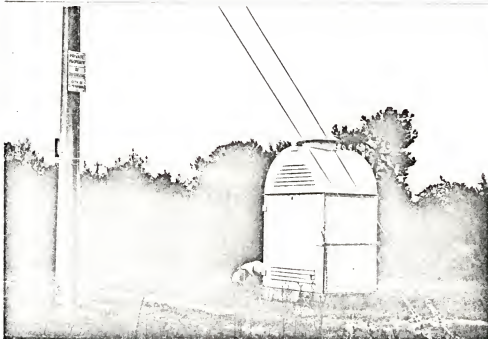


Figure 45: St. Petersburg Well Head. Numerous well heads such as that illustrated in this figure, are found throughout the Cosmi-Odessa field. As seen by the sign in this photo, ownership is by the City of St. Petersburg.

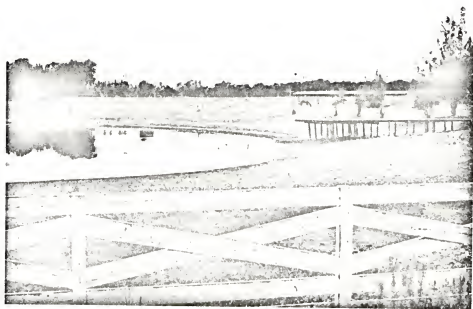


Figure 46: Lake Rogers. The southwestern extension of Lake Rogers shown here, was detached from the main body of water by August, 1972 from areal shrinkage due to ground water depletion.



Figure 47: Lake Rogers Well Head. This well head, located less than fifty yards from the original shoreline of Lake Rogers, is one of the numerous well heads which fringe the lake.

have been dredged and the impervious bottom material removed, the effects of increased pumping from the Floridan Aquifer have been aggravated.

Recently, the decrease in the level of the local artesian system has slowed the amount of dredging, but there has been increased local pumping to replenish these diminishing lake levels. Although this method of sustaining lake levels seems to merely recycle water through the natural percolation process, it does add to the regional loss of water to the atmosphere. In addition, this process also alters the biotic environment of the lake by adding a disproportionate amount of hard water to lake recharge. Therefore, continued dredging and use of this method of artificial recharge to enhance regional development should be limited until further research can determine the overall environmental impact.

The decrease in the level of the potentiometric surface of the Floridan Aquifer in the thirty year period of study in the Hillsborough River Basin has had a tendency to decrease the streamflow component of baseflow. Although expanded urbanization in the Tampa Bay Region has contributed considerably to this decrease, to conclude that the overall urban impact on the Hillsborough River has been to decrease streamflow would be premature. Before final conclusions can be reached, surface or storm runoff alterations from urbanization must be considered.

Changes in Surface Runoff

As urbanization increased in the Hillsborough River Basin from 1940 to 1970, the amount of surface area capable of infiltrating water for ground water recharge has been decreased. The large areas now covered by concrete and blacktop associated with urban growth have decreased the permeable surface area of the basin and thus increased surface runoff from precipitation. Although much of this increased runoff may drain on to permeable land, its added volume and rate of flow far exceeds the percolation rate of the permeable surface in most cases. Thus surface storage is satisfied at a more rapid rate and soil flooding along with wide spread sheet runoff occurs more frequently. A brief look at one area of rapid urban development north of the City of Tampa in the west central portion of the Hillsborough River Basin will exemplify this altered relationship.

In the last five years, commercial development along North Florida Avenue near Bearss Plaza has increased significantly. Major development has included the construction of three separate commercial areas. These are: 1) Shady Oaks Plaza (Figure 48) 2) a small office complex at 14902 North Florida Avenue (Figure 49), and 3) a Kash and Karry Supermarket (Figure 50). Shady Oaks Plaza and the office complex are located on the northwest and southwest corners of the intersection of Florida and Siobhan Avenues respectively. The Kash and Karry Market, the largest of the three developments, is located just north of and across from Shady Oaks Plaza. This supermarket with its

accompanying Kare Drugstore was completed in the fall, 1973. Presently, there are plans for expansion of this commercial facility to include a shopping center. Preliminary operations for its construction can be seen in Figure 51.

The altered hydrologic characteristics caused by these developments in the Hillsborough River Basin can be seen in the increased runoff on Siobhan Avenue after a rain. Storm runoff from North Florida Avenue and the Kash and Karry Plaza is routed through ditches and culverts (Figures 50 and 52) to a county maintained drainage easement found 130 feet south of Siobhan Avenue. Several interviews with long time residents of the street revealed that in the last ten years, there were only several occasions when any measurable amount of water could be seen in the easement. However, recent construction of the commercial areas has changed the frequency of this occurrence.

In the early summer of 1974, there was relatively heavy precipitation over the Hillsborough River Basin. In late June, after several days of frequent thunderstorms over Northern Hillsborough County, the drainage easement on Siobhan Avenue began to fill with excess runoff (Figure 53). This was the first period of intense precipitation in the area since completion of the Kash and Karry Plaza in the preceeding fall. It was also the first time that many of the residents realized the function of the drainage easement which fringed the southern boundary



Figure 48: Shady Oaks Plaza. This photo illustrates Shady Oaks Plaza. It is one of the relatively new developments on North Florida Avenue in the Bearss Plaza Area of North Tampa.



Figure 49: New Office Complex. This small office complex at 14902 North Florida Avenue is located across Siobhan Avenue from Shady Oaks Plaza. Directly behind this new development is the Siobhan Avenue drainage easement.

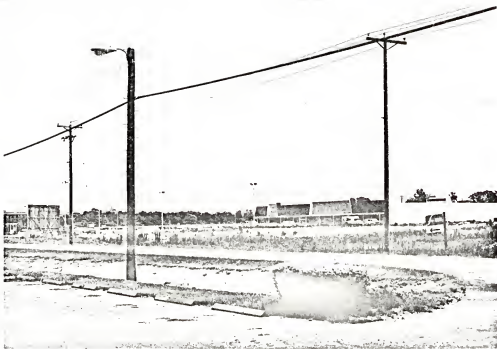


Figure 50: Kash and Karry Plaza. This photo of the new Kash and Karry Supermarket was taken from Shady Oaks Plaza. Notice the drainage ditch in the foreground which enters the Siobhan easement.



Figure 51: New Landfill on North Florida Avenue. Preliminary landfill operations have begun for construction of a small shopping center adjoining the Kash and Karry Market. Without proper precautions, this construction will add to the drainage problems of the area.



Figure 52: North Florida Avenue Drainage Culvert. The drainage culvert illustrated here has been constructed under Siobhan Avenue. Its function is to divert excess runoff from North Florida Avenue to the Siobhan easement.

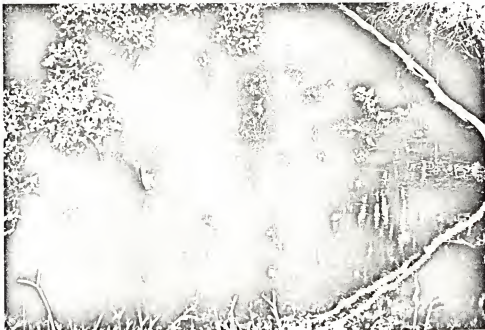


Figure 53: Siobhan Avenue Drainage Easement. In June, 1974, the Siobhan easement held water for the first time because of increased urban runoff in the area. The amount of water in the easement fluctuated slightly from the level shown here until its completion in August of that year.



Figure 54: Siobhan Avenue Flooding. Street flooding to the extent shown here is no longer uncommon on Siobhan Avenue after periods of heavy rainfall. The increased runoff creating this effect is primarily from the development of Shady Oaks Plaza on North Florida Avenue.

of their property. After the frequency of thunderstorms decreased to their normal summertime level, water still remained in the easement and began to lay stagnant.

By mid July, it was evident that all flow in the drainage facility had ceased and that in reality, the ditch was functioning as an elongated retention basin. Investigation revealed that the last two hundred yards of the drainage easement to Curiosity Creek were never completed by the county. Because this primary drainage facility functioned so rarely, residents of Siobhan Avenue were unaware of this fact until surface runoff in the area was increased by construction of the Kash and Karry Market. Numerous complaints to the County Road and Health Departments about the health hazard and mosquito infestation resulted in completion of the easement to Curiosity Creek by mid August, 1974. Since its completion, flow in this drainage ditch can be observed after every occurrence of high precipitation in the area.

Increased flow through the drainage easement south of Siobhan Avenue is not the only evidence of increased runoff from development in the area. Although Shady Oaks Plaza is separated from Florida Avenue by a drainage ditch connected to the Siobhan easement (Figure 50), the majority of storm runoff from this area does not enter the artificial drainage system directly. Rather, it flows to the west along the Siobhan Avenue pavement to the end of the street where it is diverted overland to the easement. Street

flooding of the magnitude seen in Figure 54 was rare until construction of this small commercial area.

Increased storm runoff from these newly developed areas on North Florida Avenue is presently routed to Curiosity Creek. The effect of this development on the hydrologic character of the Hillsborough River Basin has been two-fold. Primarily, increased runoff through the artificial drainage system has increased the streamflow of Curiosity Creek during storm periods. As mentioned in Chapter II, the water in this creek flows to Blue Sink in North Tampa where it is diverted underground until it surfaces again at Sulphur Springs. Thus it is added indirectly to the flow of the Lower Hillsborough River.

Secondly, this recent development has changed the recharge character of the western portion of the basin. Added streamflow to Curiosity Creek is recharging the Sulphur Springs system. This added streamflow, however, occurs at the expense of local ground water recharge in the Bearss Plaza area. In the recent drought of May, 1975, mentioned in Chapter IV, several of the shallower wells on Connie Avenue, one block north of Siobhan Avenue, went dry. This could have possibly been avoided if local ground water recharge during the preceding wet period was not decreased by increased regional water loss from urban expansion.

Problems such as those experienced in the Bearss Plaza area of North Tampa are not uncommon in the newly

developed areas of the Hillsborough River Basin. Florida Avenue just south of Siobhan is flooded from increased urban runoff during every major rainstorm. The lack of a controlled retention system and an adequate storm drainage network are related to the tax structure of suburban living. Although the lower tax base of the county compared to that of Tampa seems to be an advantage for development, the diminished number of services and facilities economically available are a disadvantage. Murphy (1966) identifies this situation as a major problem of suburban living. Hillsborough County cannot economically provide the extensive systems necessary to cope with the problems resulting from increased urban runoff. However, there are several precautions which can be taken to reduce their effect. These will be discussed in the conclusion of this study.

Combined Effects of Urbanization on Streamflow

In the previous sections of this chapter, it has been shown that urbanization both within and outside of the major study region have altered the hydrologic components of streamflow in the Hillsborough River Basin. Because of ground water depletion, overall base flow has been decreased, thus tending to decrease streamflow. At the same time during the period of this study, surface runoff has been increased from storm precipitation due to increased impermeable surface area which accompanied urban expansion. Although these relationships are evident from visual

inspection, the overall relationship between urbanization and streamflow cannot be determined without further examination of streamflow records.

As mentioned at the beginning of this chapter, over 88 percent of the Hillsborough River Basin below Tampa Dam was urbanized by 1970. However, records from the U.S. Geological Survey which show accurate streamflow measurement from this area and are suitable for this study are unavailable. Although there are several gauging stations located below the dam, their records are of little use because: 1) streamflow below the dam is tidally influenced, 2) the hydrograph response from 7.59 percent of a 690 square mile basin is negligible, 3) diversion of water above these stations for the City of Tampa water supply decreases the accuracy of measurement, and 4) precipitation over the large area measured by the stations is variable. These factors necessitate the selection of several smaller areas for comparison. These possess the desired characteristics of land use, but lack the problems encountered in analysis of streamflow in the lower Hillsborough River Basin.

In order to determine the relationship between urbanization and streamflow in the study area, it is necessary to find what portion of the variation in streamflow is explained by urban changes in the surface characteristics of the basin. Because land use data are unavailable on a yearly basis for the period of study, this relationship

will be determined indirectly by analyzing precipitation and streamflow data. As previously mentioned, two subareas have been selected for further study to determine this relationship.

The Blackwater Creek Basin has been chosen as a control area to represent an example of the hydrologic response of streamflow to precipitation in an undeveloped area. Because urban development for all practical purposes is non-existent in the basin, the relationship between precipitation and streamflow in this area will be considered normal for that of an undeveloped region. By comparing the results established for Blackwater Creek to those obtained in a physically similar, but highly urbanized basin, the relationship between urbanization and streamflow will be determined. Because the comparison will be made between undeveloped and urbanized basins, any significant difference between the relationship of precipitation and streamflow in each will be attributed to urbanization.

The Alligator Creek Basin near Safety Harbor, Florida has been selected to represent the hydrologic response of streamflow to precipitation in an urban basin. Unlike Blackwater Creek, Alligator Creek is not located within the limits of the Hillsborough River Basin. This watershed is found approximately fifteen miles west of the major study area (Figure 1), however, it meets the specific requirements necessary for this study as discussed in Chapter I.

Alligator Creek Basin - Urban Area, 1974

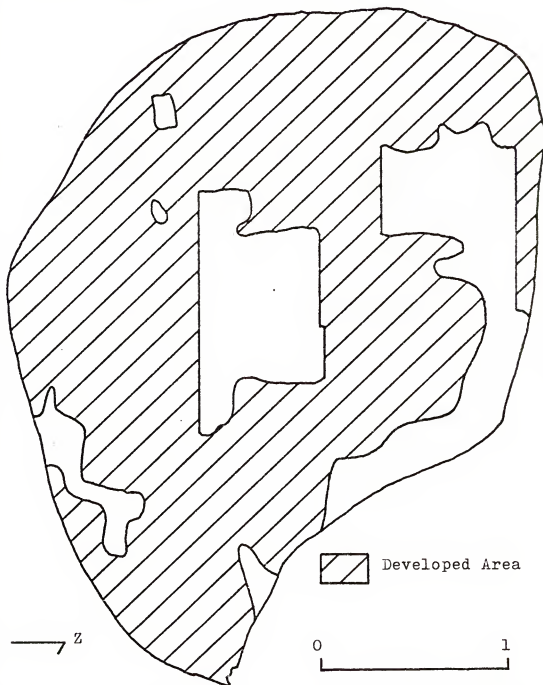


Figure 55

Urban development in the Alligator Creek Basin has been discussed in Chapter III. According to Figure 20 and Table 23, slightly over 34 percent of the region was under urban development by 1970. Inspection of Figure 55 which was compiled from the air photographs found in Appendix II, however, reveals that by November, 1974, the extent of urbanization in the area had increased significantly. By use of a simple dot grid, it has been determined that the urban area in this figure accounts for 74 percent of the total basin. Therefore, analysis of streamflow data through the 1974 water year for Alligator Creek will more closely represent the urban relationship to streamflow in the Lower Hillsborough River Basin to 1970. The urban subregion and the developed portion of the major study area below the Tampa Dam are sufficiently similar in extent of urbanization to justify comparison. Thus, the results obtained in the analysis of the two subregions should represent the relationship between urbanization and streamflow in the Hillsborough River Basin for the period of study.

Three methods of analyzing streamflow data will be used to determine the impact of urban development on streamflow in the urban subregion. These are: 1) Hydrograph Analysis, 2) Cumulative Curve Analysis, and 3) Regression Analysis. In each case, the results obtained from Alligator Creek will be compared to those obtained from Blackwater Creek. This will determine the relative difference between streamflow relationships in an urban basin and in an unaltered basin.

Hydrograph Analysis

Hydrograph analysis is valuable in determining the rate at which peak discharge is reached and maintained in a stream. From the discussion of peak flows in Chapter I, it has been established that peak discharge is attained rapidly and held for a relatively short period of time in an urban basin. It has also been established that streams draining an undeveloped area will reach peak discharge from a storm much more slowly and maintain high flow for a longer period of time than urban streams. Examination of the hydrographs compiled from streamflow data of Alligator and Blackwater Creeks reveals that these general trends are slightly modified in the subregions of this study.

Figure 56 illustrates a storm hydrograph from Alligator Creek in September, 1950. At that time, less than ten percent of the basin was under urban development (Figure 20). Peak discharge of 445 cfs from this storm was reached in two days and took approximately 5.5 days to dissipate. Comparison of this figure with the hydrograph from Blackwater Creek in December, 1969 (Figure 57) reveals that the two are similar. Peak discharge of 483 cfs in the rural control basin was attained in two days and dissipated over an eight day period. The longer period for removal of storm runoff in Figure 57 may be attributed to the large size of the Blackwater Creek Basin. Because both hydrographs reach peak flow and dissipate storm runoff at a

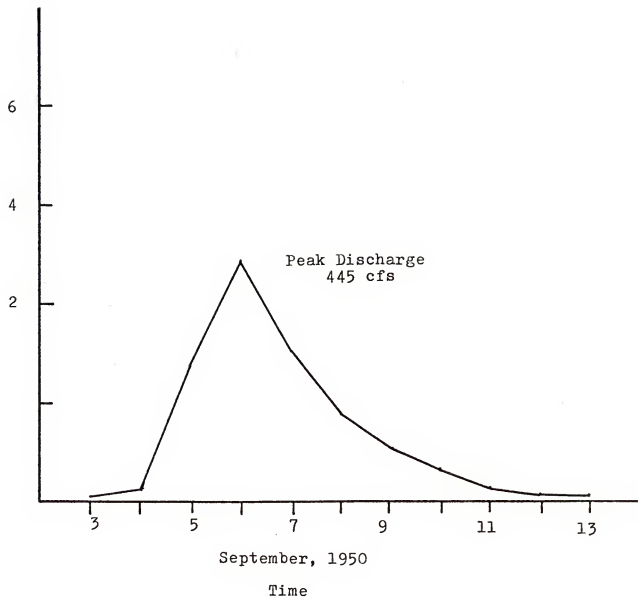


Figure 56: Alligator Creek - Storm Hydrograph,
Less Than 10% Urban

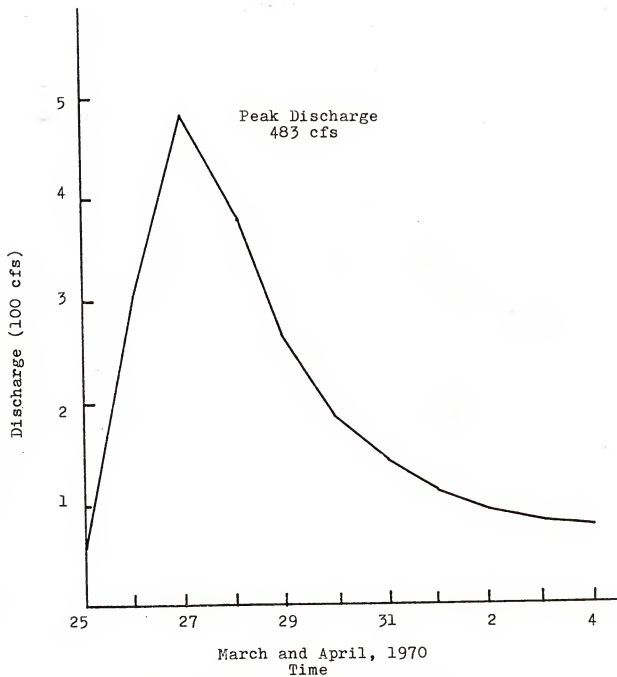


Figure 57: Blackwater Creek - Storm Hydrograph

relatively slow rate, they illustrate the response of an undeveloped basin to storm runoff.

The storm hydrograph seen in Figure 58, however, reveals a different response of streamflow to storm runoff. This figure illustrates a graphic representation of streamflow in Alligator Creek in June, 1974 when 74 percent of the area was urbanized. Although peak discharge was also attained in two days in this graph, the relatively slow rise in the hydrograph is attributed to the cumulative effect of several days of precipitation. The urban response to storm runoff in this case is best seen in the brief maintenance of increased flow. Peak flow of 1030 cfs, the highest ever recorded in the basin, was dissipated rapidly in 2.5 days. This clearly illustrates the response of a highly urbanized basin to storm runoff.

From the three hydrographs shown here, it can be seen that in 1950 the response of Alligator Creek to storm runoff was that of an undeveloped basin. By 1974, however, urban development had altered the hydrologic reaction of the basin to high precipitation. Although this general trend can be identified, the available data lacks the necessary detail to illustrate the intense reaction expected from urban runoff as seen in Chapter I.

Miller (1966) and Seaburn (1969) have used hydrograph analysis to illustrate urban effects on streamflow in their respective studies. Reexamination of Figure 3 and 4 will show that in each case the researchers have used hourly

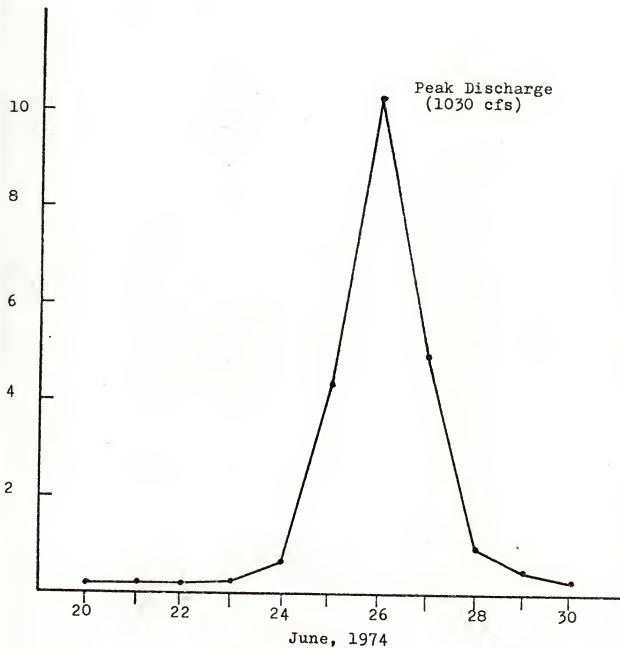


Figure 58: Alligator Creek - Storm Hydrograph, 74% Urban

discharge data to construct their hydrographs. Detailed data of this type, however, was not available for Alligator and Blackwater Creeks. The hydrographs in this section, therefore, were constructed by using the available daily discharge records for each station.

Storm hydrographs compiled from daily data cannot show rapid peak development from urban runoff as well as hourly hydrographs. For example, peak discharge from a storm may be attained in one day in both rural and urban situations. Although this peak may be reached in two hours in an urban basin as compared to twenty hours in a rural basin, the daily hydrograph will show that they reached peak flow simultaneously. General trends may be derived from the hydrographs in this section, but further investigation is necessary to more accurately determine the impact of urbanization on streamflow in the Alligator Creek and Hillsborough River Basins.

Cumulative Curve Analysis

From the hydrograph analysis in the previous section of this chapter, it has been determined that urbanization in the Alligator Creek Basin has decreased regional water retention by increasing streamflow during storm periods. Similar effects were concluded from field observations in the urban area near Bearss Plaza in North Tampa. This analysis, however, does not examine the impact of ground water depletion on low flow periods and thus fails to determine the overall effect of urbanization on streamflow for

the period of record. It is therefore necessary to examine precipitation and streamflow data for the entire period of record in each sub-basin to determine any differences in this relationship.

One method of examining the relationship between precipitation and streamflow involves plotting the cumulative curves for each variable on the same graph. Comparison of the relative trends of each will show the general relationship of precipitation and streamflow in each subarea. In order to establish the unaltered relationship of these variables in the Hillsborough River Basin, Blackwater Creek will be examined first according to this method of analysis.

Figure 59 shows the cumulative curves of streamflow and precipitation in the Blackwater Creek Basin for the water years 1952-1974. Streamflow was measured by a U.S.G.S. recording gauge located 4.4 miles west of Knights, Florida on State Highway 39 (Note 4). Precipitation data was provided by the U.S. Weather Bureau for Plant City. Although this station is located outside of the subarea, it is located within eight miles of the streamflow recording gauge. For the most part, the trend lines for each of the variables in Figure 59 are parallel. This feature of the cumulative curves reflects a continuous close relationship between precipitation and streamflow in the area for the period of record. The only exception to the parallel character of these curves is found during the 1959 and 1960

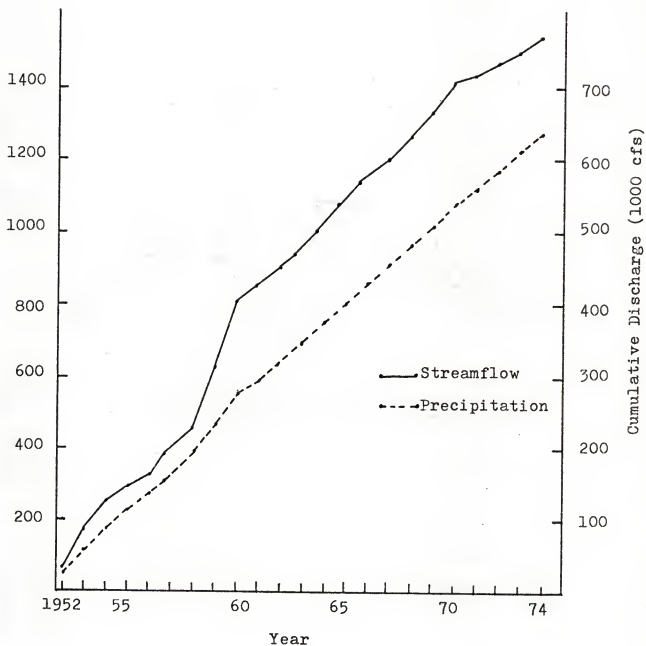


Figure 59: Cumulative Curves - Blackwater Creek Basin

water years. The significant upward surge in streamflow which occurs at this point may be explained by the floods of that period discussed in Chapter IV.

Close inspection of the precipitation curve will also reveal a slight upward surge in the 1959 and 1960 water years created by several periods of unusually high rainfall. Its effect on streamflow, however, may be explained by the nature of the precipitation. The floods of that period were created by high intensity precipitation of relatively short duration. Therefore, the infiltration capacity of the rural basin was satisfied quickly which caused a rapid increase in surface runoff or streamflow. Although annual precipitation was somewhat above normal for this period, annual streamflow totals were greatly increased from these flood flows. From 1960-1974, the cumulative curves once more approach a parallel pattern, thus reflecting the positive relationship between precipitation and streamflow in the undeveloped basin.

Figure 60 illustrates the cumulative precipitation and streamflow curves of Alligator Creek for water years 1950-58 and 1961-74. Streamflow records for water years 1959 and 60 were unavailable because of the discontinuous records of the station. Because of this fact, precipitation data for this period was also deleted from the cumulative precipitation curve. Streamflow measurements were recorded by the U.S.G.S. Gauge located thirty feet upstream from Bayshore Drive and 0.8 miles southwest of Safety Harbor,

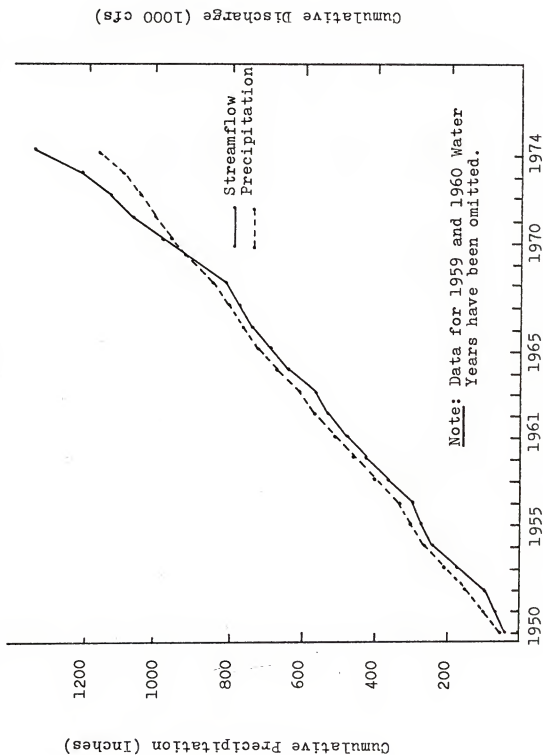


Figure 60: Cumulative Curves - Alligator Creek Basin

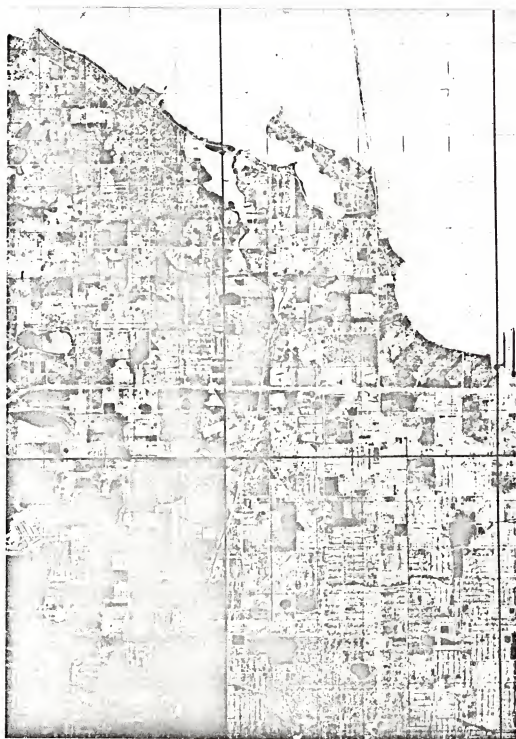
Florida (Note 4). Precipitation data was obtained from the U.S. Weather Bureau for Clearwater and Clearwater Beach. These stations are located several miles west of the basin, but represent the closest source of precipitation data for the area.

Inspection of the trend lines in Figure 60 reveals that the relationship between precipitation and streamflow in the Alligator Creek Basin to 1968 was similar to that of Blackwater Creek. Until that point, the precipitation and streamflow curves increased at a similar rate. After 1968, however, streamflow increased at a significantly higher rate with no marked difference in the rate of precipitation increase. This reveals a change in the relationship between the two variables.

Comparison of the development maps of Alligator Creek (Figures 20 and 55) along with the air photos in Figure 61 (Alligator Creek Basin, 1965) and Appendix II will illustrate the rate of urban development in the basin. Figures 20 and 61 show that between 1965 and 1970 there was a ten percent increase in urbanization in this sub-region from approximately 24 percent to 34 percent. Further inspection of Appendix II shows that between 1970 and 1974 urbanization increased from 34 percent to 74 percent around Alligator Creek. Thus in the 10-year period 1965-74, urbanization increased fifty percent in the sub-region. The increased slope of the cumulative streamflow curve from 1968 to 1970 in Figure 60 is attributed to the

Figure 61: Alligator Creek Basin, 1965

Photograph Scale, 1:56,320



rapid rate of urban development in the basin. From these illustrations it can be seen that overall streamflow in Alligator Creek has increased with expanded urbanization in the basin. In order to determine the extent to which urbanization has altered streamflow in the area, it is necessary to further analyze the available data.

Regression Analysis

The first two methods of analysis have shown that streamflow has increased with expanded urban development in the Alligator Creek Basin. It is the purpose of this final method of analysis to determine what portion of the variation in streamflow is explained by variation in precipitation in both the rural and urban subregions. Once this determination is made, the relationship between urbanization and streamflow will be ascertained indirectly. This will be accomplished by use of simple linear regression and correlation analysis of streamflow and precipitation data for Both Alligator and Blackwater Creek Basins.

Regression analysis and related correlation analysis involves a multi-step process. The basic procedures of this process include: 1) calculation of the regression equation, 2) determination of variation characteristics, and 3) calculation of the coefficient of determination. Before analysis of the data for Alligator and Blackwater Creeks takes place, a brief discussion of the formulas and method of analysis will be helpful in understanding the process.

The regression line is plotted according to the formula:

$$(1) \quad Y = a + bX$$

where Y is the dependent variable (streamflow), X is the independent variable (precipitation), a is the Y intercept of the regression line, and b is the regression coefficient or the slope of the regression line. Because of the method of calculating the regression constants, a and b, the regression equation is determined by the nature of the relationship between streamflow and precipitation. Determination of the values for a and b may best be accomplished by first establishing a set of intermediate parameters according to the formulas*:

$$(2) \quad Sx^2 = \sum X^2 - \frac{(\sum X)^2}{n} \quad \text{and}$$

$$(3) \quad Sxy = \sum XY - \frac{(\sum X)(\sum Y)}{n}$$

Using these parameters, it is now possible to determine the values of the regression constants as follows:

$$(4) \quad b = \frac{Sxy}{Sx^2} \quad \text{and}$$

$$(5) \quad a = \bar{Y} - b\bar{X}$$

Determination of the regression equation is the first step of analysis. After this has been accomplished, it is

* The formulas and basic notation used in this section are those used in a class in Quantitative Geographic Methods given at the University of South Florida in 1971. Although notation may vary from that used in some standard texts, the processes involved are in the accepted form for regression and correlation analysis.

then necessary to ascertain the nature of variation in the relationship between streamflow and precipitation within the subareas. This may be done according to the following formulas.

$$\begin{array}{ll}
 (6) & S_y^2 - S_Y^2 - YSY \text{ (called the total} \\
 & \text{variation)} \\
 (7) & S_y^2 + bS_{xy} \text{ (called the explained} \\
 & \text{variation)} \\
 (8) & S_y^2 - S_y^2 - S_y^2 \text{ (called the unex-} \\
 & \text{plained variation)}
 \end{array}$$

S_y^2 refers to total variation in the dependent variable.

S_y^2 refers to the variance in the dependent variable that can be explained by variation in the independent variable.

S_y^2 refers to the variance in the dependent variable that cannot be explained by variation in the independent variable.

The relationship between the parameters discussed to this point may be seen in Figure 62. Given any point (X, Y), the variation of streamflow from the mean ($\bar{Y}$) for the period of record may be determined graphically according to one of the following criteria: 1) total variation (V_T) is the distance from point X, Y to the mean, 2) explained variation (V_E) is the distance between the regression line and mean, and 3) unexplained variation (V_U) is the distance from point X Y to the regression line. Therefore, the variation of each set of streamflow and precipitation values may be determined by plotting a scatter diagram of measured points on the regression graph.

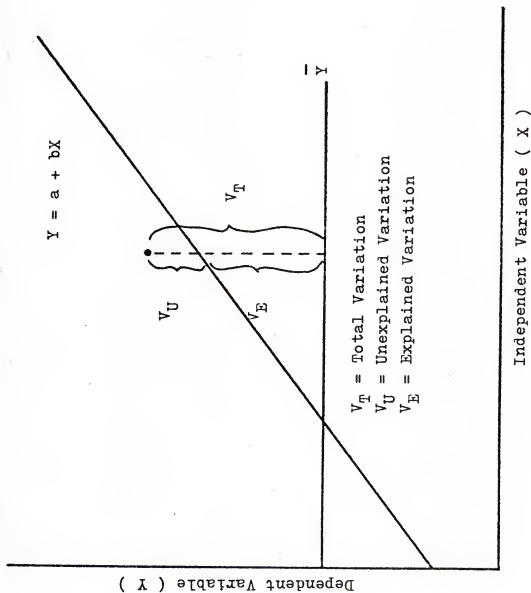


Figure 62: Regression Graph

It is now possible to graphically determine the annual variation in streamflow from regression analysis. Total variation and explained variation of data for the period of record are also known at this point in the procedure. However, it is now necessary to determine what portion of the total variance is explained. This may be done by the simple percentage process in the following formula;

$$(9) \quad r^2 = \frac{Sy_c^2}{Sy^2}$$

where r^2 is the coefficient of determination, Sy_c^2 is the explained variation for the period (formula 7), and Sy^2 is the total variation for the period (formula 6). The coefficient of determination is a critical value for this study because it represents the percentage of variation in the dependent variable (streamflow) that is explained by variation in the independent variable (precipitation). Once this value has been established for the natural situation in the Hillsborough River Basin (Blackwater Creek), it can be compared to the value calculated for the urban situation of Alligator Creek. Because of the nature of the two basins, the resulting difference between the two coefficients of determination will represent the percentage of variation in streamflow that is explained by variation in urban development.

Simple linear regression and associated correlation analysis were carried out for Blackwater Creek according to the method outlined above. The data analyzed and the

necessary calculation of critical parameters can be found in Appendix III. By the use of formulas 1, 4 and 5, the regression equation for the subregion was found to be

$$(1) \quad Y = -51.71 + 1.55 X$$

The line of this equation has been plotted on the regression graph in Figure 63 along with the scatter diagram of observed annual precipitation and streamflow measurements for the period of record. The distribution of these points around the regression line in this figure demonstrates visual evidence of a high positive correlation between streamflow and precipitation in this basin. By substitution of the values calculated for total and explained variation for Blackwater Creek (Appendix III) in formula 9 the coefficient of determination was calculated as follows:

$$(9) \quad r^2 = \frac{8577.47}{10049.4}$$

$$r^2 = 0.8535$$

Therefore, from regression and correlation analysis, it has been determined that the unaltered relationship between the two tested variables is such that 85.35 percent of the total variation in streamflow in the Hillsborough River Basin is explained by variation in precipitation over the basin. It is now necessary to determine the relationship between streamflow and precipitation in the Alligator Creek Basin where major urban development has altered the surface characteristics of the area.

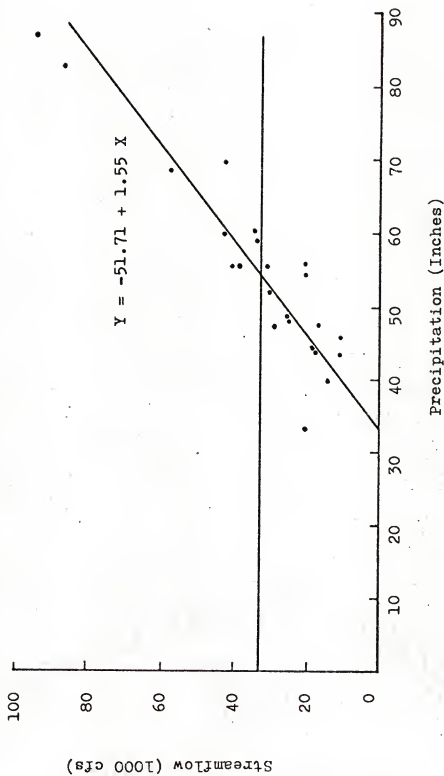


Figure 63: Regression Graph - Blackwater Creek

Using the same procedures for regressions and correlation analysis that were used in Blackwater Creek, calculations were carried out for Alligator Creek data. These data and calculations can be found in Appendix III. The regression constants, a and b, were established according to formulae 4 and 5. By substituting these values in formula 1, the regression equation was determined as

$$(1) \quad Y = -2.37 + 0.104 X$$

Figure 64 illustrates the graphic representation of this equation along with the scatter diagram of annual streamflow and precipitation measurements for the period of record. Visual inspection of the distribution of these points around the regression line reveals that a lower degree of correlation exists between these variables in the Alligator Creek Basin than in the Blackwater Creek Basin as seen in Figure 62. After establishing the values for total variation (S_y^2) and explained variation (S_{yc}^2) according to formulae 6 and 7, the coefficient of determination was calculated as follows:

$$(9) \quad \begin{aligned} r^2 &= \frac{21.23}{40.6} \\ r^2 &= 0.5229 \end{aligned}$$

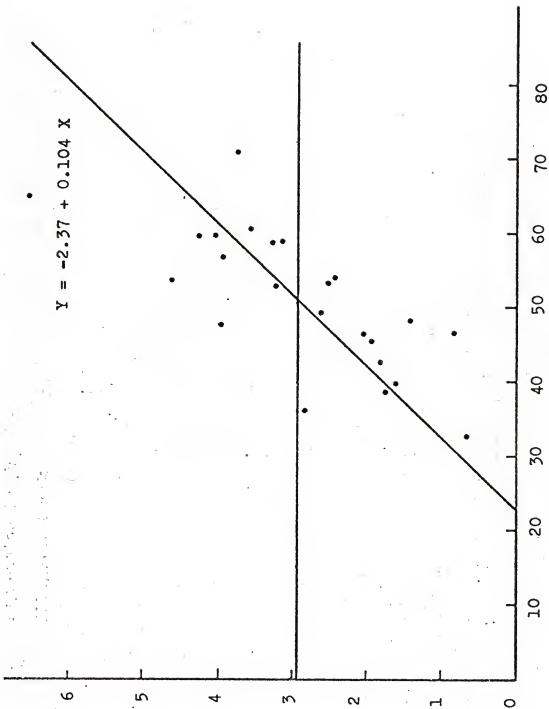
Therefore, according to this method of analysis, the relationship between streamflow and precipitation in the Alligator Creek Basin, which represents the urbanized portion of the Hillsborough River Basin, is such that,

$$Y = -2.37 + 0.104 X$$

Streamflow (1000 cfs)

Precipitation (Inches)

Figure 64: Regression Graph - Alligator Creek



52.29 percent of the total variation in streamflow is explained by variation in precipitation over the region.

It has already been established that under natural conditions, 85.35 percent of the total variation of streamflow in the Hillsborough River Basin is explained by variation in precipitation. It has now been determined that in an area of significant urban development, only 52.29 percent of this variation is explained. Therefore, in accordance with the premise set forth previously in this paper, it can now be estimated that urbanization in the Hillsborough River Basin has accounted for 33.06 percent of the total variation in streamflow for the period of record.

Before this conclusion can be firmly established, the coefficients of determination must be tested for significance to insure that they did not occur by chance and to determine that they are significantly different.* The

* According to Dr. Roy Francis of the University of South Florida, the straightest forward test of two independent unbiased estimates of variance is an F-Test using the following form:

$$F = Sy_{cr}^2 / Sy_{cu}^2 \quad df = N-3/N-2$$

where Sy_{cr}^2 is the explained variation in the rural basin

and Sy_{cu}^2 is the explained variation in the urban basin (df represents the method of calculating degrees of freedom for the test). This test was run to determine the significance of the results from regression and F was established as 404.03. From comparison of this statistic with a standard F table at $df = 20/21$ the conclusion was

final test selected for this purpose was a Critical Ratio Test or a form of T-Test as described by McCormick (1941). The mechanics of this statistical test may be found in Appendix III. The Critical Ratio or T statistic was calculated to equal 2.2216. Comparison of this computed statistic with the values on a standard T table at infinite degrees of freedom reveals that there is a significant difference between the two correlation coefficients at the five percent level of significance. Thus, with 95 percent certainty, the results from regression represent a valid relationship and did not occur by chance.

Conclusions

It has been established that between 1940 and 1970, there was significant urban expansion in the Hillsborough River Basin. Inspection of the changes in the potentiometric surface of the Floridan Aquifer and local levels of the ground water table has revealed that urbanization outside of the general study area has affected the hydrologic character of the region. In addition, local changes in the surface configuration of the basin, such as those seen in the Bearss Plaza Area, have had a tendency to increase storm runoff, alter ground water recharge areas, and increase actual water loss in the regional hydrologic system.

reached that the results from regression were valid. However, the magnitude of the F statistic reflected the sizable difference in streamflow quantity between the two basins. Therefore, another test was necessary that would eliminate the influence of streamflow magnitude on the statistic.

By using several methods of examining streamflow and precipitation data for rural and urban subregions, it has been established that overall streamflow has increased with expanded regional urbanization. From the discussion of the general relationships of the Hydrologic Cycle in Chapter II, it is known that the quantity of regional streamflow is dependent upon: 1) the quantity of precipitation, 2) ground water relationships (Base flow), and 3) surface characteristics. Considering that the two subregions examined were physically similar (with the general exception of area), but culturally different, regression analysis concluded that slightly over 33 percent of the variation in streamflow for the period of record was determined by variation in urbanization. The implications of this relationship between urbanization and streamflow in the Hillsborough River Basin are important when examining regional water problems.

It has been shown that as urbanization has increased, baseflow (the primary component of streamflow during low flow periods in the Hillsborough River) has tended to decrease. Thus, streamflow is further diminished during natural low flows. In addition, peak flows have increased during flood periods and, as a result of unrestricted flood plain development, the costs attributed to flood damage have risen. There has also been a greater demand for water to accommodate the consumptive needs of the increased population associated with expanded urban development. Much of this represents a reduction in streamflow.

Figure 65 and the related statistics in Table 30 illustrate the projected extent of urban development in Hillsborough County by the year 1990. Analysis of the localized data provided by the Hillsborough County Planning Commission shows that approximately 35 percent of the total projected population increase and about 46 percent of the total projected land required to accommodate this population will be within the limits of the Hillsborough River Basin. Simple arithmetic computations show that the total urban area of the Hillsborough River Basin will increase by over 25,900 acres. Considering the established effects of urban development on the hydrologic character of the region, it is obvious that a comprehensive water program is necessary for the area, if serious water problems are to be avoided.

One of the primary problems associated with the regional water budget and urbanization stems from the usual method of urban runoff disposal. The traditional method of controlling increased runoff from development has been by means of storm sewers and drainage ditches. These concentrate storm runoff in artificial channels to shunt excess water to nearby natural channels or streams. Thus, developers and a poorly informed public as a whole, may feel that the problem of storm water disposal has been solved when it has been merely shifted. The mere rerouting of storm water for quick removal from the scene is not

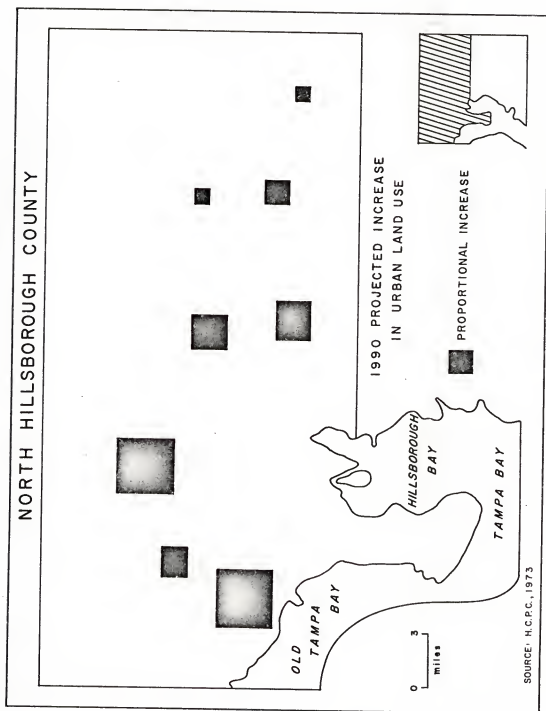


Figure 65

Table 30: Projected Urban Land Use and Population - Hillsborough County, Florida

	1972		1980		1990	
	acres		acres	% increase over 1972	acres	% increase over 1972
Urban Land Use						
1) Residential Use	59,000		79,700	35.1	102,000	72.9
Single Family	53,000		65,000	22.6	78,000	47.2
Multi Family	2,000		7,400	270.0	14,000	600.0
Mobile Home	4,000		7,300	82.5	10,000	150.0
2) Commercial Use	6,900		9,400	36.2	13,000	88.4
3) Industrial Use	13,200		14,600	10.6	17,500	32.6
4) Public and Semi-Public	10,500		12,000	14.3	13,500	28.6
Total Developed Area	89,600		115,700	29.1	146,000	62.9
Population	#	#	#	#	#	#
	490,256		667,190	36.1	871,769	77.8

Source: Hillsborough County Planning Commission, 1973

the answer. Rather, a method of controlled storm water retention to insure a degree of local ground water recharge and to diminish water loss to the area is more appropriate. Furthermore, such retention stabilizes surface flow.

Several aspects of the Four River Basins Plan, as discussed in Chapter IV, provide such treatment of storm runoff. The Big Cypress and portions of the Lower Hillsborough Flood Detention Areas will function as ground water recharge areas for proposed well fields in the basin. Water retained in the Green Swamp Flood Detention Area will also recharge the ground water table of all four major basins in the project area.

Erratic seasonal streamflow distribution has historically presented the problem of feast or famine for the regional water supply of the Hillsborough River Basin. Suitable surface water storage to satisfy the present and future needs of the population as outlined in the 1962 Four River Basins Plan is economically impractical because of the restrictions of topography and the relatively high potential evapotranspiration of the region. Because of the numerous problems involved in establishing a network of reservoirs to provide adequate flood control as well as a suitable water supply, the Tampa Bay Regional Planning Council has suggested that no value be given to the F.R.B. Project when considering the future regional water supply for Hillsborough County (Briley et al., 1970).

In view of the recent modifications to the plan, however, this assumption can no longer be considered valid. The reduced level of the potentiometric surface of the Floridan Aquifer since 1949 in the Hillsborough River Basin necessitates provisions for additional ground water recharge to the system in order to maintain a viable source of fresh water for the region. The revised Four River Basins Plan has established such provisions. In addition, the modifications to the Tampa Bypass Canal mentioned in Chapter IV, furnish the capability of diverting flood flows from the urban areas of the lower basin and adding in-directly to the regional water supply. Because of these recent changes in the plan, the Four River Basins Project will aid in reducing the adverse effects of urbanization on streamflow and related hydrologic characteristics of the Hillsborough River Basin.

Although this plan provides an acceptable regional water program for the study area, further precautionary actions are necessary to further minimize regional flood damage and the local effects of urban development such as those described in the Bearss Plaza area of North Tampa. In conjunction with the regional plan, strict controls for floodplain development should be established to decrease the potential for urban flood damage. Also, legislation should be enacted at the county level which would require drainage control and provisions for water retention for large developments.

As previously mentioned, Hillsborough County cannot economically provide the extensive drainage facilities necessary to accommodate increased surface runoff from urban development. Rather this cost should be deferred to the developer. In the Bearss Plaza area of North Tampa, construction of a relatively small retention basin by the Kash and Karry Market chain would reduce the impact of increased surface runoff and thus reduce or prevent local flooding on Siobhan Avenue. This facility would compensate somewhat for the adverse hydrologic effect created by development by once more providing natural ground water recharge as well as tending to normalize surface flow. By the combination of recommended precautions, and implementation of the revised Four River Basins Project, the adverse influence of urbanization on the hydrologic characteristics of the Hillsborough River Basin will be diminished if not neutralized.

APPENDIX I

PROCEDURES USED TO CALCULATE POTENTIAL EVAPOTRANSPIRATION IN THE HILLSBOROUGH RIVER BASIN

The nomogram and tables listed in this section are used to calculate regional potential evapotranspiration. The procedures for its computation outlined below, are those used by C.W. Thornthwaite in "An Approach Toward a Rational Classification of Climate", Geographical Review, Vol. 38, 1948, pp. 55-94. Tables 31, 32 and 33 are partial listings of Tables 1, 5 and 6 respectively from; Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance, C.W. Thornthwaite and J.R. Mather, Drexel Institute of Technology Laboratory of Climatology, Centerton, New Jersey, 1957.

The following steps should be used to determine annual regional potential evapotranspiration.

Step 1: Look for 80°F or higher mean monthly temperatures.

- a. If all months exceed 80°F, use Table 32 and omit Table 31.
- b. If any month has less than 80°F, begin with Table 31 and return to Table 32 in Step 5.

Step 2: In Table 31, find the values of i corresponding to mean monthly temperatures. Total the values of i to determine I .

- Step 3: Extend a straight line from the Point of Convergence at $T = 26.5^{\circ}\text{C}$, $PE = 13.5$ cm through the determined I value on the Heat Index scale on the Nomogram (Figure 66).
- Step 4: Convert mean monthly temperature from $^{\circ}\text{F}$ to $^{\circ}\text{C}$. Determine monthly unadjusted PE by extending the mean monthly temperature ($^{\circ}\text{C}$) along the ordinate to the nomogram line. Read unadjusted PE in centimeters along the abscissa from the point of intersection. Convert centimeter reading to inches.
- Step 5: For temperatures greater than 80°F , read unadjusted PE directly from Table 32.
- Step 6: Determine adjusted PE by multiplying each monthly unadjusted PE value by the appropriate factor from Table 33 corresponding to the latitude of the area (Tampa is approximately 28°N). For latitudes beyond 50° , use the values for 50° .
- Step 7: Add the twelve monthly adjusted PE values to establish the total annual adjusted PE.

Table 31: Monthly Values of i Corresponding to Monthly Mean Temperatures

T °F	0	.2	.4	.6	.8	T °F	0	.2	.4	.6	.8
32			.01	.01	.02	67	7.82	7.88	7.95	8.02	8.09
33	.04	.05	.06	.07	.09	68	8.16	8.23	8.29	8.36	8.44
34	.10	.12	.14	.16	.17	69	8.50	8.57	8.64	8.71	8.78
35	.19	.21	.23	.25	.27	70	8.86	8.92	8.99	9.07	9.14
36	.29	.32	.34	.36	.38	71	9.21	9.27	9.35	9.42	9.50
37	.41	.44	.46	.48	.51	72	9.57	9.64	9.71	9.79	9.86
38	.54	.57	.60	.62	.65	73	9.93	10.00	10.08	10.16	10.23
39	.69	.71	.74	.78	.81	74	10.30	10.38	10.45	10.53	10.60
40	.83	.87	.90	.93	.97	75	10.67	10.75	10.83	10.90	10.97
41	1.00	1.03	1.07	1.10	1.14	76	11.05	11.13	11.21	11.28	11.36
42	1.18	1.21	1.24	1.29	1.32	77	11.44	11.51	11.59	11.66	11.74
43	1.35	1.40	1.43	1.47	1.51	78	11.82	11.90	11.97	12.05	12.13
44	1.55	1.58	1.63	1.66	1.70	79	12.22	12.30	12.37	12.45	12.53
45	1.75	1.78	1.83	1.87	1.91	80	12.61	12.68	12.77	12.85	12.93
46	1.95	2.00	2.04	2.08	2.13	81	13.01	13.09	13.17	13.25	13.33
47	2.16	2.21	2.25	2.30	2.34	82	13.41	13.41	13.58	13.66	13.74
48	2.39	2.44	2.48	2.53	2.57	83	13.82	13.90	13.98	14.07	14.15
49	2.62	2.67	2.71	2.76	2.81	84	14.23	14.32	14.40	14.49	14.57
50	2.86	2.90	2.95	3.00	3.05	85	14.65	14.73	14.82	14.90	14.98
51	3.10	3.15	3.20	3.25	3.30	86	15.07	15.16	15.24	15.33	15.41
52	3.35	3.40	3.45	3.50	3.56	87	15.49	15.58	15.66	15.75	15.84
53	3.61	3.66	3.71	3.76	3.82	88	15.93	16.01	16.10	16.19	16.27
54	3.87	3.93	3.98	4.03	4.08	89	16.35	16.44	16.53	16.62	16.71
55	4.14	4.19	4.25	4.31	4.36	90	16.80	16.88	16.97	17.05	17.14
56	4.42	4.47	4.53	4.58	4.64	91	17.23	17.32	17.41	17.50	17.59
57	4.69	4.75	4.82	4.87	4.93	92	17.55	17.77	17.85	17.94	18.03
58	4.98	5.04	5.10	5.16	5.21	93	18.12	18.22	18.31	18.40	18.49
59	5.28	5.34	5.39	5.46	5.52	94	18.58	18.66	18.76	18.85	18.94
60	5.58	5.63	5.70	5.75	5.82	95	19.03	19.12	19.22	19.31	19.40
61	5.88	5.94	6.00	6.07	6.13	96	19.49	19.58	19.67	19.77	19.86
62	6.19	6.25	6.31	6.38	6.45	97	19.96	20.05	20.14	20.24	20.32
63	6.50	6.57	6.63	6.69	6.76	98	20.42	20.51	20.61	20.70	20.80
64	6.83	6.89	6.95	7.02	7.08	99	20.89	20.99	21.08	21.17	21.27
65	7.15	7.22	7.28	7.35	7.42	100	21.36	21.46	21.56	21.65	21.75
66	7.48	7.55	7.62	7.69	7.75	101	21.84	21.94	22.03	22.13	22.23

Table 32: Monthly Values of Unadjusted Potential Evapo-
transpiration at Temperatures Above 80°F

T °F	.0	.2	.4	.6	.8
79				5.31	5.36
80	5.39	5.43	5.47	5.50	5.54
81	5.58	5.61	5.65	5.69	5.72
82	5.76	5.80	5.83	5.86	5.90
83	5.93	5.96	6.00	6.03	6.06
84	6.08	6.12	6.16	6.18	6.21
85	6.24	6.27	6.30	6.33	6.36
86	6.39	6.40	6.44	6.47	6.50
87	6.52	6.55	6.57	6.60	6.62
88	6.64	6.67	6.69	6.71	6.73
89	6.75	6.78	6.80	6.82	6.83
90	6.86	6.87	6.90	6.91	6.94
91	6.95	6.96	6.99	7.00	7.02
92	7.03	7.05	7.07	7.08	7.09
93	7.10	7.11	7.12	7.14	7.15
94	7.16	7.18	7.19	7.19	7.20
95	7.21	7.22	7.23	7.23	7.24
96	7.24	7.24	7.25	7.25	7.25
97	7.26	7.26	7.26	7.26	7.27
98	7.27	7.27	7.27	7.27	7.27
99	7.28	7.28	7.28	7.28	7.28

Table 33: Mean Possible Duration of Sunlight in the Northern Hemisphere
Expressed in Units of 30 Days of 12 Hours Each

N Lat.	J	F	M	A	M	J	J	A	S	O	N	D
0	1.04	.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
5	1.02	.93	1.03	1.02	1.06	1.03	1.06	1.05	1.01	1.03	.99	1.02
10	1.00	.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	.98	.99
15	.97	.91	1.03	1.04	1.11	1.08	1.12	1.08	1.02	1.01	.95	.97
20	.95	.90	1.03	1.05	1.13	1.11	1.15	1.11	1.02	1.00	.92	.94
25	.93	.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	.99	.91	.91
28	.91	.88	1.03	1.07	1.17	1.16	1.18	1.13	1.03	.98	.90	.90
30	.90	.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	.98	.89	.88
35	.87	.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	.97	.86	.85
40	.84	.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	.96	.83	.81
45	.80	.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	.94	.79	.75
50	.74	.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	.92	.76	.70

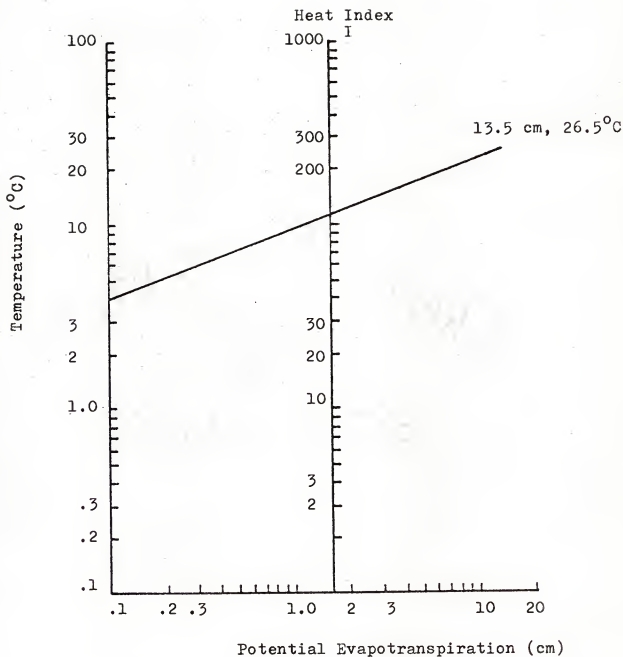


Figure 66: Nomogram - Hillsborough River Basin

APPENDIX II

URBAN DEVELOPMENT IN THE ALLIGATOR CREEK BASIN, NOVEMBER, 1974

The following air photographs illustrate the extent of urban development in the Alligator Creek Basin as of November 11, 1974. The relative location of each photograph within the region is shown in Figure 79. The photos shown here are at the scale, 1 : 14,400.

Figure 67: Alligator Creek Basin -
Section A, Figure 79

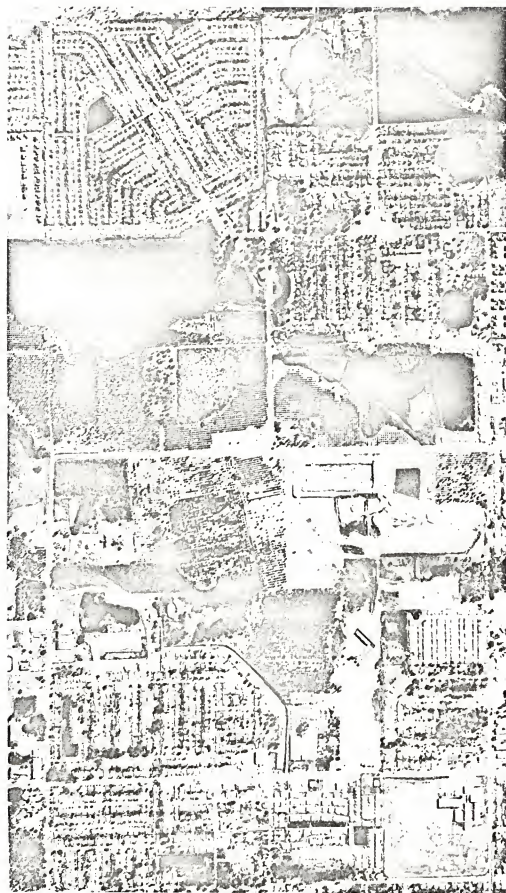


Figure 68: Alligator Creek Basin -
Section B, Figure 79

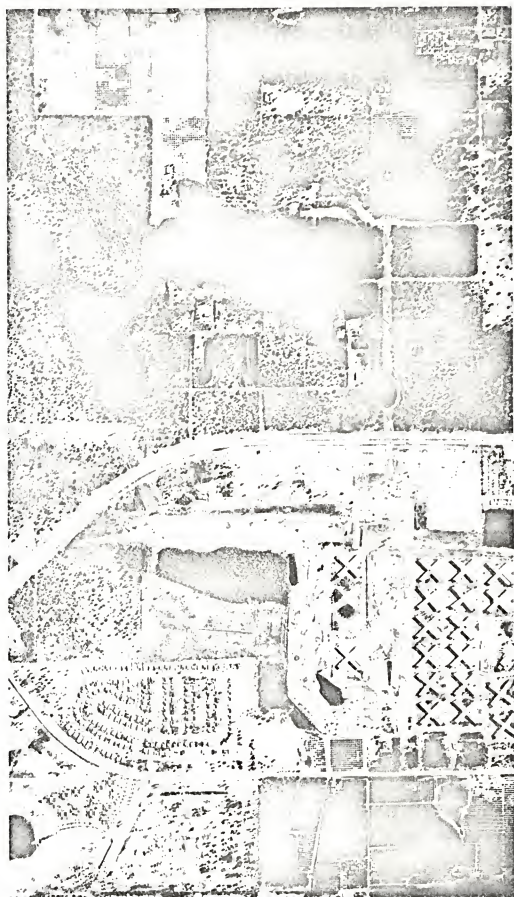


Figure 69: Alligator Creek Basin -
Section C, Figure 79



Figure 70: Alligator Creek Basin -
Section D, Figure 79



Figure 71: Alligator Creek Basin -
Section E, Figure 79



Figure 72: Alligator Creek Basin -
Section F, Figure 79



Figure 73: Alligator Creek Basin -
Section G, Figure 79



Figure 74: Alligator Creek Basin -
Section H, Figure 79

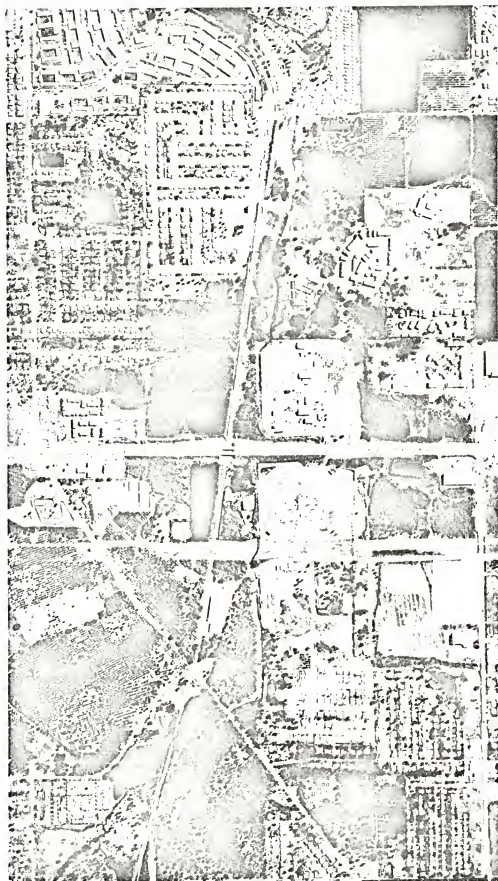


Figure 75: Alligator Creek Basin -
Section I, Figure 79



Figure 76: Alligator Creek Basin -

Section J, Figure 79

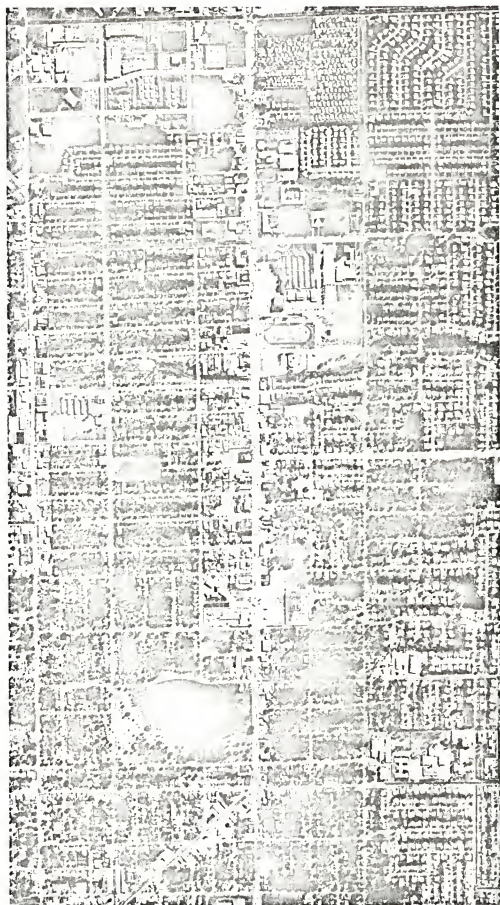


Figure 77: Alligator Creek Basin -
Section K, Figure 79



Figure 78: Alligator Creek Basin -
Section L, Figure 79



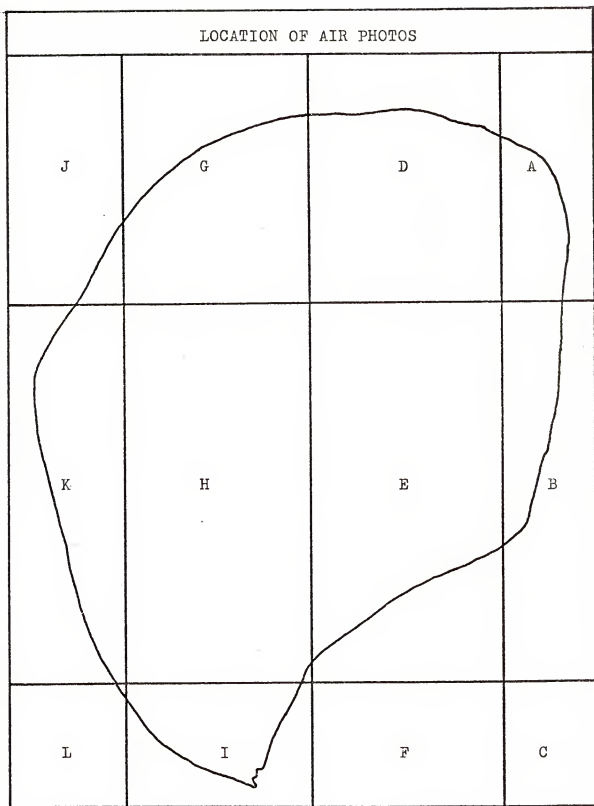


Figure 79

APPENDIX III

DATA TABLES AND BASIC COMPUTATIONS OF
STATISTICAL ANALYSIS

Table 34: Determination of Adjusted Potential Evapotranspiration - Hillsborough River Basin

	J	F	M	A	M	J	J	A	S	O	N	D	Tot.
Temperature °F	61.2	62.7	66.0	71.4	76.8	80.6	81.6	82.0	80.5	74.7	66.8	62.3	
Temperature °C	16.2	17.1	18.9	22.0	24.9					23.6	19.4	16.8	
i (Table 31)	5.94	6.41	7.48	9.35	11.36	12.85	13.25	13.41	12.81	10.56	7.75	6.22	117.39
Un. PE (Figure 66)	3.7	4.5	6.0	8.6	12.0					10.4	6.4	4.3	
Un. PE (Inches)	1.46	1.77	2.36	3.38	4.72	5.5*	5.69*	5.76*	5.48*	4.09	2.52	1.69	
Correction Factor (Table 35)	0.91	0.88	1.03	1.07	1.17	1.16	1.18	1.13	1.03	0.98	0.90	0.90	
Adj. PE (inches)	1.33	1.56	2.43	3.62	5.52	6.38	6.71	6.51	5.64	4.01	2.27	1.52	47.5

* For months with average temperature over 80°F, unadjusted PE is determined from Table 32.

Table 35: Streamflow and Precipitation Data in the Blackwater Creek Basin

Dependent Variable- Streamflow (1,000 cfs) Y	Independent Variable- Precipitation X	Y^2	X^2	XY	Water Year
27.292	46.88	744.85	2197.73	1279.45	1952
58.462	69.21	3417.81	4790.02	4046.16	1953
42.856	60.53	1836.64	3663.88	2594.07	1954
17.054	47.38	290.84	2244.86	808.02	1955
15.295	40.85	233.94	1668.72	624.80	1956
42.140	69.58	1775.78	4841.38	2932.10	1957
24.635	48.49	606.88	2351.28	1194.55	1958
86.636	82.36	7507.80	6783.17	7135.34	1959
94.062	87.05	8847.66	7577.70	8188.10	1960
20.315	33.00	412.70	1089.00	670.40	1961
20.665	54.20	427.04	2937.64	1120.04	1962
24.351	49.12	592.97	2412.77	1196.12	1963
40.208	55.12	1616.68	3038.21	2216.26	1964
31.143	55.29	969.89	3056.98	1721.90	1965
33.942	58.83	1152.06	3460.97	1996.81	1966
18.472	45.22	341.21	2044.85	835.30	1967
30.546	51.98	933.06	2701.92	1587.78	1968
34.634	60.14	1199.51	3616.82	2081.89	1969
38.526	55.37	1484.25	3065.84	2133.18	1970
11.361	45.69	129.07	2087.58	519.08	1971
11.676	43.21	136.33	1867.10	504.52	1972
21.523	55.94	463.24	3129.28	1204.00	1973
18.913	45.29	357.70	2051.18	856.57	1974

Table 36: Regression Analysis of Blackwater Creek

Basic Values

$$n = 23 \quad (\text{Number of Samples})$$

$$SY = 764.707$$

$$\bar{Y} = 33.25$$

$$SX = 1260.73$$

$$\bar{X} = 54.81$$

$$SY^2 = 35,475.91$$

$$SX^2 = 72,678.88$$

$$SXY = 47447.44$$

$$Sx^2 = SX^2 - \bar{X}SX = 72,678.88 - 69,100.61 = 3578.27$$

$$Sy^2 = SY^2 - \bar{Y}SY = 35,475.91 - 25,426.51 = 10,049.40$$

$$Sxy = SXY - \bar{X}\bar{Y} = 47,447.44 - 41,913.59 = 5533.85$$

Regression

$$b = Sxy / Sx^2 = 5533.85 / 3578.27 = 1.55$$

$$a = \bar{Y} - b\bar{X} = 33.25 - (1.55)(54.81) = 33.25 - 84.96 = -51.71$$

The Regression Equation is: $Y = -51.71 + 1.55X$

Correlation

$$Sy_c^2 = bSxy = (1.55)(5533.85) = 8577.47$$

$$r^2 = Sy_c^2 / Sy^2 = 8577.47 / 10049.40 = 0.8535$$

Table 37: Streamflow and Precipitation Data in the Alligator Creek Basin

Dependent Variable- Streamflow (1,000 cfs) Y	Independent Variable- Precipitation X	Y^2	X^2	XY	Water Year
2.503	53.18	6.27	2828.11	133.11	1950
0.850	46.34	0.72	2147.40	39.39	1951
1.439	48.05	2.07	2308.80	69.14	1952
4.051	59.39	16.41	3527.17	240.59	1953
3.243	52.89	10.52	2797.35	171.52	1954
1.614	39.56	2.61	1564.99	63.85	1955
0.694	32.83	0.48	1077.81	22.78	1956
3.750	70.80	14.06	5012.64	265.50	1957
3.252	58.31	10.58	3400.06	189.62	1958
1.936	45.23	3.75	2045.75	87.57	1961
3.140	58.61	9.86	3435.13	184.04	1962
2.067	46.11	4.27	2126.13	95.31	1963
3.543	60.02	12.55	3602.40	212.65	1964
2.472	50.39	6.11	2539.15	124.56	1965
2.681	49.06	7.19	2406.88	131.53	1966
1.748	38.69	3.06	1496.92	67.63	1967
1.813	42.29	3.29	1788.44	76.67	1968
4.259	59.01	18.14	3482.18	251.32	1969
4.623	53.13	21.37	2822.80	245.62	1970
3.990	47.22	15.92	2229.73	188.41	1971
2.881	36.06	8.30	1300.32	103.89	1972
3.962	56.68	15.70	3212.62	224.57	1973
6.512	64.33	42.41	4138.35	418.92	1974

Note: Streamflow data for water years 1959 and 1960 was not available.

Table 38: Regression Analysis of Alligator Creek

 Basic Values

 $n = 23$ (Number of Samples)

 $\overline{SY} = 67.023$
 $\overline{Y} = 2.91$
 $\overline{SX} = 1168.18$
 $\overline{X} = 50.79$
 $SY^2 = 235.64$
 $SX^2 = 61,291.13$
 $SXY = 3608.19$
 $Sx^2 = SX^2 - \overline{X}SX = 69291.13 - 59331.86 = 1959.27$
 $Sy^2 = SY^2 - \overline{Y}SY = 235.64 - 195.04 = 40.60$
 $Sxy = SXY - \overline{X}SY = 3608.19 - 3404.10 = 204.09$

Regression

 $b = Sxy / Sx^2 = 204.09 / 1959.27 = 0.104$
 $a = \overline{Y} - b\overline{X} = 2.91 - (0.104)(50.79) = 2.91 - 5.28 = -2.37$

 The Regression Equation is: $Y = -2.37 + 0.104X$

Correlation

 $Sy_c^2 = bSxy = (0.104)(204.09) = 21.23$
 $r^2 = Sy_c^2 / Sy^2 = 21.23 / 40.60 = 0.5229$

The following statistical procedure was used to test the difference between the two correlation coefficients for the urban (r_u) and rural (r_r) basins. The method used was that outlined for a Critical Ratio Test by Thomas C. McCormick, Elementary Social Statistics, New York, 1941.

Step 1: Convert the correlation coefficients r_u and r_r to Z statistics (Table 5, pg. 307, McCormick, 1941).

$$r_u = 0.723 \text{ becomes } Z_u = 0.9139$$

$$r_r = 0.924 \text{ becomes } Z_r = 1.6157$$

Step 2: Determine the standard error of Z according to the formula,

$$E_z = 1 / (N-3)^{1/2}$$

Thus,

$$\begin{aligned} E_{zu} &= 1 / (23-3)^{1/2} \\ &= 1 / 4.472 \end{aligned}$$

$$E_{zu} = 0.2236$$

and,

$$\begin{aligned} E_{zr} &= 1 / (23-3)^{1/2} \\ &= 1 / 4.472 \end{aligned}$$

$$E_{zr} = 0.2236$$

Step 3: Calculate an intermediate parameter E_D^2 .

$$\begin{aligned} E_D^2 &= (E_{zu})^2 + (E_{zr})^2 \\ &= (0.2236)^2 + (0.2236)^2 \\ &= 0.0499 + 0.0499 \end{aligned}$$

$$E_D^2 = 0.0998$$

Step 4: Calculate the Critical Ratio according to the formula

$$\text{C.R.} = Z_r - Z_u / E_D^2)^{1/2}$$

Thus,

$$\begin{aligned}\text{C.R.} &= 1.6157 - 0.9139 / (0.0998)^{1/2} \\ &= 0.7018 / 0.3159\end{aligned}$$

$$\text{C.R.} = 2.2216$$

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BIOGRAPHICAL SKETCH

Peter Salvatore Segretto was born in Oswego, New York, August 7, 1947. His elementary and secondary education were completed in that city upon graduation from Oswego Catholic High School in June, 1965. In September, 1965, he entered the University of Buffalo and later completed his Bachelor's Degree in Geography at the State University of New York, College at Oswego in 1970. During the summer, 1970, Mr. Segretto was employed as an air pollution control researcher with the Alcan Aluminum Corporation. In August of that year, he accepted a graduate assistantship at the University of South Florida and completed his Master of Arts in geography in 1971. In 1972, Mr. Segretto entered the Graduate School of the University of Florida for additional graduate work toward the degree of Doctor of Philosophy in geography. He became a candidate for that degree in 1974.

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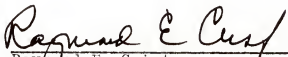
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Clark I. Cross, Chairman
Associate Professor of
Geography

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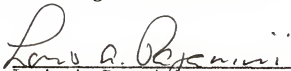
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